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A study of the resistance characteristics of ships with high displacement-length ratios

Desel, Robert F.; Collins, John T.

Massachusetts Institute of Technology

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A Study of the Resistance
Characteristics of Ships with
High Displacement-Length Ratios
by

Robert F. Desel, Lieutenant, USN
John T. Collins, Lieutenant, USN

Thesis Supervisor
Assistant Professor M.A. Abkowitz

15 May 1952

thesis
45

THESIS
D45

1905
U. S. Naval Academy
Monterey, California



A STUDY OF THE RESISTANCE CHARACTERISTICS OF SHIPS
WITH HIGH DISPLACEMENT-LENGTH RATIOS

By

Robert F. Desel
Lieutenant, U. S. Navy
B. S. University of Michigan
(1943)

John T. Collins
Lieutenant, U. S. Navy
B. S. United States Naval Academy
(1945)

Submitted to the Department of Naval Architecture
And Marine Engineering On 15 May 1952 In
Partial Fulfillment of the Requirements for the Degree of
Naval Engineer
at the
Massachusetts Institute of Technology
1952

A STUDY OF THE RESISTANCE CHARACTERISTICS OF SHIPS

WITH HIGH DISPLACEMENT-LENGTH RATIOS

Cambridge, Massachusetts
15 May 1952

Professor Joseph S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the Degree of Naval Engineer, we submit herewith a thesis entitled, "A Study of the Resistance Characteristics of Ships with High Displacement-Length Ratios".

Respectfully,

Robert F. Desel
Lieutenant
U. S. Navy

John T. Collins
Lieutenant
U. S. Navy

Washington, D.C.
12 May 1951

Professor Joseph A. Roth
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the degree
of Master of Science, we submit herewith a thesis entitled
"A Study of the Political Organization of Japan with
High School-Level English Proficiency".

Respectfully,

Robert A. Roth
Lieutenant
U. S. Navy

John T. Collins
Lieutenant
U. S. Navy

A STUDY OF THE RESISTANCE CHARACTERISTICS OF SHIPS
WITH HIGH DISPLACEMENT-LENGTH RATIOS

By

Robert F. Dassel and John T. Collins

Submitted to the Department of Naval Architecture and Marine Engineering on 13 May 1952 in partial fulfillment of the requirements for the degree of Naval Engineer.

ABSTRACT

The authors present a series of contours for estimating residual resistance coefficients of ships whose displacement-length ratios are above those considered in Taylor's Standard Series. These contours cover a range of displacement-length ratios from 280 to 560, volume-length ratios from 8 to 16, and longitudinal prismatic coefficients from .58 to .70. In addition, a curve is provided for estimating wetted surface coefficients of these ships.

The data for this study were taken from 44 ship model tests that have been conducted at the David W. Taylor Model Basin over a period of years. These models in no way form a systematic series. Their hull forms are related only to the extent provided by overall coefficients such as the displacement-length ratio, prismatic coefficient and beam-draft ratio.

The residual resistance coefficients for each model were calculated from the original test data using the Schoenherr friction formulation. These coefficients were used to determine average contours of volume-length coefficient on coordinates of prismatic coefficient and residual resistance coefficient at various Froude number values.

It should be emphasized that the resulting contours represent an average of the data from the 44 ship models studied. No particular model conforms exactly to the contours. To further stress this point, the calculated model data are plotted with the contours.

The contours as determined in this study indicate an optimum with regard to residual resistance coefficient at a prismatic coefficient of about .58. At this value of prismatic coefficient, the variation of residual resistance with prismatic coefficient is very slight. The contours also indicate that the variation of residual resistance coefficient with volume-length ratio at the optimum prismatic value is considerably less than at higher values of prismatic coefficient.

[illegible]

Journal of Management Education

Submitted for publication April 10, 1961; accepted for publication May 1, 1961.

2542 WU

[illegible]

The date for this study was early 1964. At this time, the first data were collected at the level of the local health care system. These data are in the form of a questionnaire which will become available only to the extent provided by the local health care system. The data are in the form of a questionnaire which will become available only to the extent provided by the local health care system.

The original relationship was developed for a small number of individuals from the original data using the following relationship formulae. These relationships were used to determine average values of variously weighted components of individual weights and various weights components of

It should be emphasized that the preceding analysis is based on the assumption that the data are stationary. If the data are non-stationary, the results may be biased. In this case, the data should be detrended or differenced before being analyzed.

The following is a list of the names of the persons who have been
 appointed to the various committees of the Board of Directors of the
 American Telephone and Telegraph Company, for the year ending
 December 31, 1911.

It is believed that the results of the study will be of value to designers in selecting hull form coefficients and for estimating the resistance of new designs. However, the data must be used with discretion, bearing in mind that it is an average of individual ships whose variations of resistance with details of design have not been completely evaluated.

The fact that definite trends in the resistance characteristics of the ships studied are evident indicates that it would be highly desirable to conduct a standard series type investigation in the region of high displacement-length ratios.

Thesis Supervisor: Prof. M. A. Abkowitz
Assistant Professor of Naval Architecture

It is believed that the results of this study will be of value to designers in selecting and designing ventilation and air conditioning systems. However, the data must be used with discretion, bearing in mind that it is an average of individual cases and not a prediction of results. Details of design have not been completely evaluated.

The first and primary reason for the ventilation and air conditioning of the room studied was to provide a healthy and comfortable environment for the occupant. The second reason was to provide a means of removing heat and moisture from the room.

Resident Supervisor, Mrs. A. L. Smith
Assistant Professor of Mechanical Engineering

ACKNOWLEDGEMENTS

The authors of this thesis are indebted to many people for the encouragement and assistance rendered in the course of the study. They are particularly indebted to Dr. F. H. Todd of the David Taylor Model Basin for suggesting the work, and for his continuing advice and encouragement. They wish to express their gratitude to Captain H. E. Saunders, U. S. N. of the Bureau of Ships for his interest and advice. They are grateful to the Staff of the David Taylor Model Basin whose endeavours greatly facilitated the work. They acknowledge with special thanks, the assistance rendered by their thesis supervisor, Professor M. A. Abkowitz.

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I. NOMENCLATURE

Displacement-Length Ratio

$$\frac{\Delta}{(L/100)^3}$$

Displacement in tons of salt water at 59° F divided by the cube of one percent of the length in feet

Volume-Length Ratio

$$\frac{\nabla}{(.1L)^3}$$

Volume of displacement divided by the cube of ten percent of the length (nondimensional)

Residual Resistance Coefficient

$$C_R = \frac{R_R}{1/2 \rho S V^2}$$

Residual resistance divided by the product of one half, the mass density of water, wetted surface and velocity squared (nondimensional)

Longitudinal Prismatic Coefficient

$$C_p = \frac{\nabla}{A_m L}$$

Volume of displacement divided by the product of the midship section area and the length (nondimensional)

Beam-Draft Ratio

$$\frac{B}{H}$$

The ratio of beam to draft (nondimensional)

Block Coefficient

$$C_b = \frac{\nabla}{LBH}$$

Volume of displacement divided by the product of length, beam, and draft (nondimensional)

Froude Number

$$V/\sqrt{gL}$$

Velocity divided by the square root of the product of length and the acceleration of gravity (nondimensional)

Wetted Surface Coefficient

$$C_{SW} = S/\sqrt{\nabla L}$$

Wetted surface divided by the square root of the product of volume of displacement and length

II. FORMULAS

Displacement-Correction Factor

$$\frac{\Delta}{(L^2/100)^2}$$

Displacement in mm of wire
under an 80% T divided by the
cube of one percent of the
length in feet

Volume-Correction Factor

$$\frac{\Delta}{(L/10)^3}$$

Volume of displacement divided
by the cube of the percent of
the length (inches)

Partial Surface Coefficient

$$R = \frac{A}{L^2 \sqrt{100}}$$

Partial surface divided by
the product of one half the area
divided by square root of length
and velocity (inches/second)

Longitudinal Partial Coefficient

$$R = \frac{\Delta}{L^2}$$

Volume of displacement divided by
the product of the square of the
area and the length (inches)

Shear-Correction Factor

$$\frac{\Delta}{L}$$

The ratio of shear to length
(inches)

Mass Coefficient

$$C = \frac{\Delta}{L^3}$$

Volume of displacement divided by
the product of length, area, and
length (inches)

Young's Modulus

$$\frac{E}{L}$$

Volume divided by the square root
of the product of length and the
acceleration of gravity (inches/second)

Partial Surface Coefficient

$$R = \frac{\Delta}{L^2}$$

Partial surface divided by the square
root of the product of length and
displacement (inches)

II. INTRODUCTION

There is a great lack of published data on the resistance characteristics of ships with high displacement-length ratios. This study is presented in an effort to provide some guides in a relatively unmarked area of hull design.

At present designers of ships with high displacement-length ratios rely primarily on their individual experience for the selection of suitable form parameters for new designs. Estimates of the resistance characteristics of new designs must be made almost entirely by comparisons with the relatively few ships of this type that fall within the designer's experience, or from individual model tests. The evaluation of the merits of any design are difficult because of the lack of any standard of comparison, such as Taylor's Standard Series provides at lower displacement-length ratios (below 250).

The first step in filling this void of information on high displacement-length ratio ships was taken by the Japanese after World War II. In the interests of the Japanese fishing industry, a standard series of model tests were conducted. The parent form for this series was a fishing vessel of the Tuna and Bonita Clipper type. The results of these experiments were published in 1950 and have come to be known as the "Takagi Series" in this country. The prototype for this series, however, is a very special type of vessel and can hardly be considered as representing high displacement-length ratio ships in general. The application of these results is, therefore, somewhat limited.

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War II. In the interests of the Japanese fishing industry, a series of model tests were conducted. The results from this series was a fishing vessel of the Tama and Hama classes. The results of these experiments were published in 1950 and have come to be known as the "Tama Series" in this country. The prototype for this series, however, is a very special type of vessel and can hardly be considered as representative of high displacement-length ratio ships in general. The application of these results is, therefore, somewhat limited.

Even though there has been a lack of systematic data on the ships with high displacement-length ratios, there has been an accumulation of what might be called "scattered data" on this type of ship over the years. This data is the result of individual model experiments conducted at the David Taylor Model Basin and at the United States Experimental Model Basin over the past thirty years.

It is the purpose of this study to assemble and systematize, as far as possible, the accumulation of "scattered data" on ships with high displacement-length ratios.

From these data there has been a lack of systematic data on

the effect of light displacement on the growth of the plant.

As a result of this study it is concluded that the effect of

light displacement on the growth of the plant is not significant.

These results are in agreement with the results of other studies.

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significant. It is the purpose of this study to determine the effect of

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study are in agreement with the results of other studies.

III. PROCEDURE

The models to be used in this study were selected primarily on the basis that their displacement-length ratios were above 250. In order to eliminate any ships of peculiar form and to have the fullness as indicated by the high displacement-length ratio, represent a general fullness rather than just a fullness of beam, the selection was further restricted to models whose beam-draft ratio values were between two and three. The examination of the lines of the selected ships confirmed the logic of this choice in that they were all of generally ship-shape form. This selection yielded 44 models.

The original test data for each of the 44 models were assembled and these data were used to calculate values of residual resistance coefficient at various Froude numbers. The Schoenherr friction formulation was used throughout this work. The length of model used to compute Reynolds and Froude numbers was taken in each case as the actual water line length at the displacement of the test. This work provided sufficient information for plotting residual resistance versus Froude number curves for each model.

The residual resistance coefficient was selected as the basic resistance parameter. This choice was based on several factors:

1. It is a generally accepted parameter in this country.
2. Ships of the high displacement-length type are relatively short in comparison to their speeds and are, therefore, operating in ranges of Froude number where wave making resistance is of primary importance.

III. RESULTS

The results to be used in this study are selected primarily on the basis that their displacement-length ratios were above 200. In order to eliminate any effect of hull form on the results, only hulls as indicated by the high displacement-length ratios, were used. A general conclusion rather than a definite one, the selection was further restricted to hulls whose beam-to-length ratios were between two and three. The examination of the lines of the selected ships confirmed the logic of this choice in that they were all of generally ship-like form. This selection yielded 44 models.

The original test data for each of the 44 models were assembled and these data were used to calculate values of various resistance coefficients of various kinds. The following list of coefficients was used throughout this work. The length of model used to compute Reynolds and Froude numbers was taken as the actual water line length at the displacement of the test. This was provided sufficient information for plotting resistance versus Froude number curves for each model.

The resistance coefficient was defined as the ratio of resistance to wetted area. This choice was based on several factors. 1. It is a generally accepted practice in this country. 2. None of the high displacement-length type are relatively short in comparison to their transverse and longitudinal dimensions in range of Froude number where wave making resistance is of primary importance.

3. The residual resistance coefficient offers a satisfactory spread of values to differentiate resistance characteristics among these models.
4. It has a nondimensional form.

Froude number was selected as the speed parameter because of its nondimensional form. The parameters that were selected to define the hull form were the volume-length ratio and the longitudinal prismatic coefficient. These parameters were selected primarily because they gave the most favorable orientation of the resistance data with respect to hull form. Several other hull form parameters were considered, including length-beam ratio, beam-draft ratio, vertical prismatic coefficient, waterplane coefficient, and midshipsection coefficient. None of these, however, provided a good orientation among the models. It is not presumed that the selected parameters are the best. Further study might produce parameters that would provide a better orientation of models. However, it is felt that the improvement on parameters representing hull form would involve such items as the position of the center of buoyancy, angle of entrance of the load waterline, or entrance prismatic coefficient. These values could not be included in this study because they were not available for most of the models.

Using the selected parameters, contours of constant displacement-length ratio were faired on coordinates of prismatic coefficient and residual resistance coefficient at various Froude numbers. In fairing these contours the controlling factor was that they represent a good average of the available data. The averaging to arrive at these

3. The original position of the object is not

known or known to differ from the position

of the object.

4. It is a mechanical form.

These objects are related to the world by means of

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the world are the objects that are related to the

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6

contours was accomplished by eye. These contours were then cross-faired against constant prismatic coefficient, and constant residual resistance coefficient.

In addition a wetted surface coefficient was calculated for each model based on the square root of the volume-length product. This coefficient was plotted against midship section coefficient. An average curve was drawn through these points. This curve can be used to estimate the wetted surface coefficients of similar vessels.

and the other two are the same. The other two are the same.

negotiated under the Labor I

[illegible]

and the other 1000 are in the *unseen* set.

IV. RESULTS

- A. Contours of volume-length ratio on coordinates of longitudinal prismatic coefficient versus residual resistance coefficient at various Froude numbers.
- B. Curve of average wetted surface coefficient versus midship section coefficient.

1995-1996

1. The first of these is the fact that the
theoretical coefficient of variation is
the same for all values of ρ . This is
because the variance of the sample mean
is proportional to $1/n$, and the variance
of the sample variance is proportional to
 $1/n$. The theoretical coefficient of
variation is therefore proportional to
 $1/\sqrt{n}$, and is the same for all values
of ρ .

FIGURE 1

$$\frac{V}{L} = .20$$

$$\frac{\Delta}{(L)^2}$$

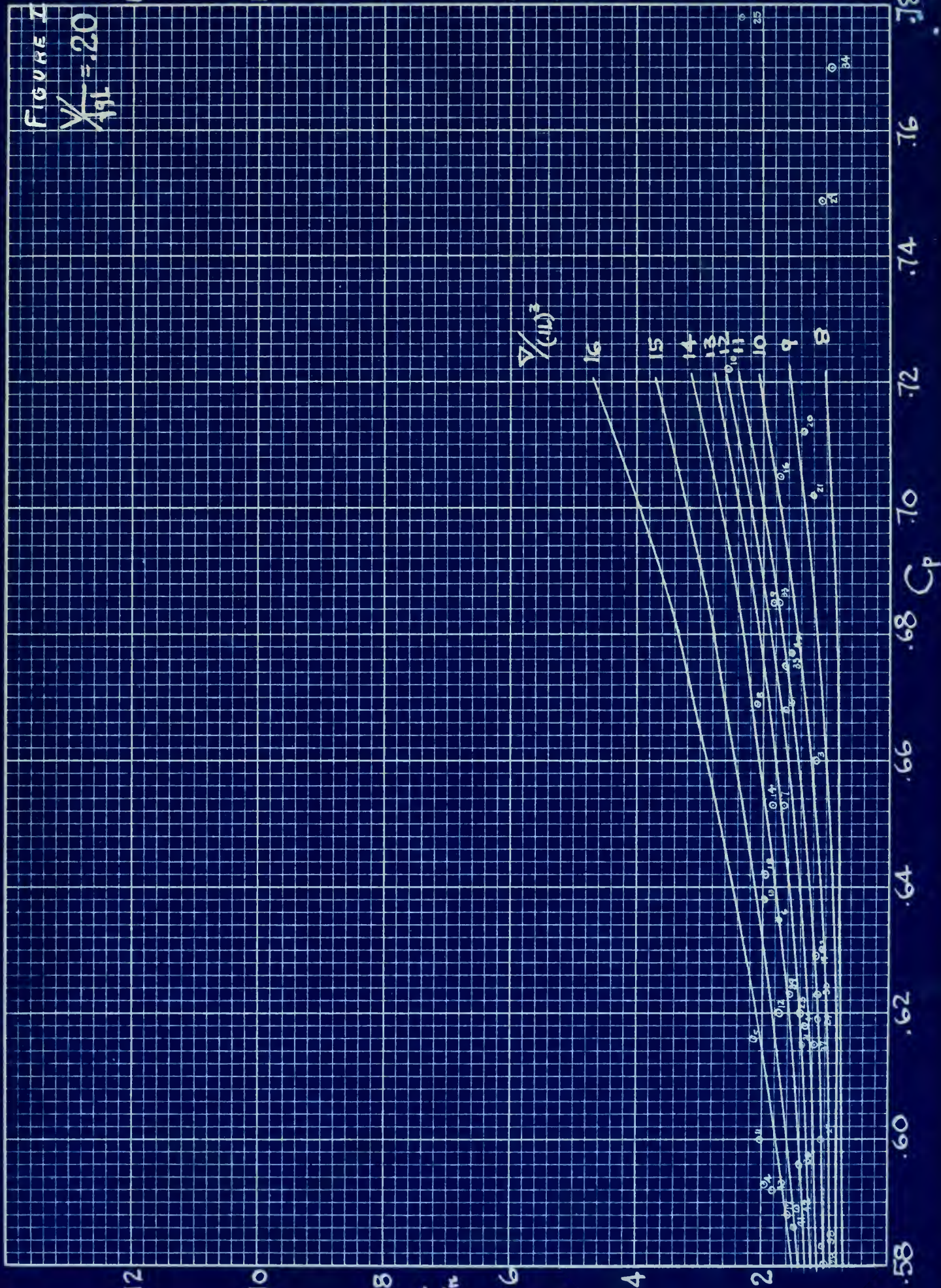


FIGURE II

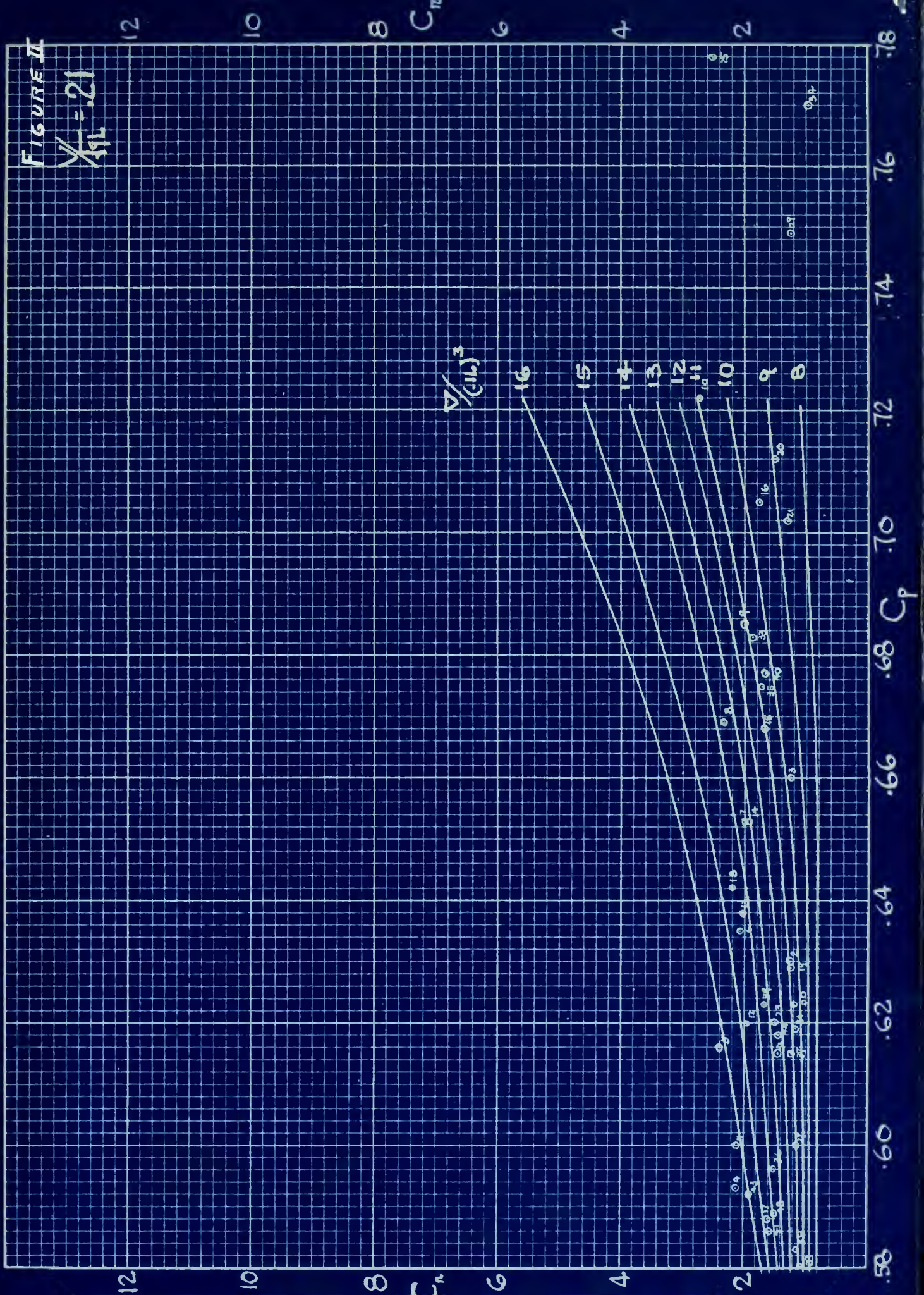
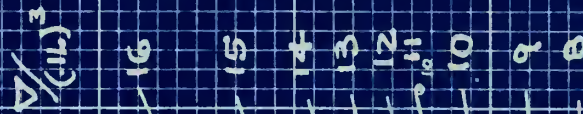
$$\frac{15}{12} = 21$$


FIGURE III
 $\frac{191}{\Delta} = 2.2$

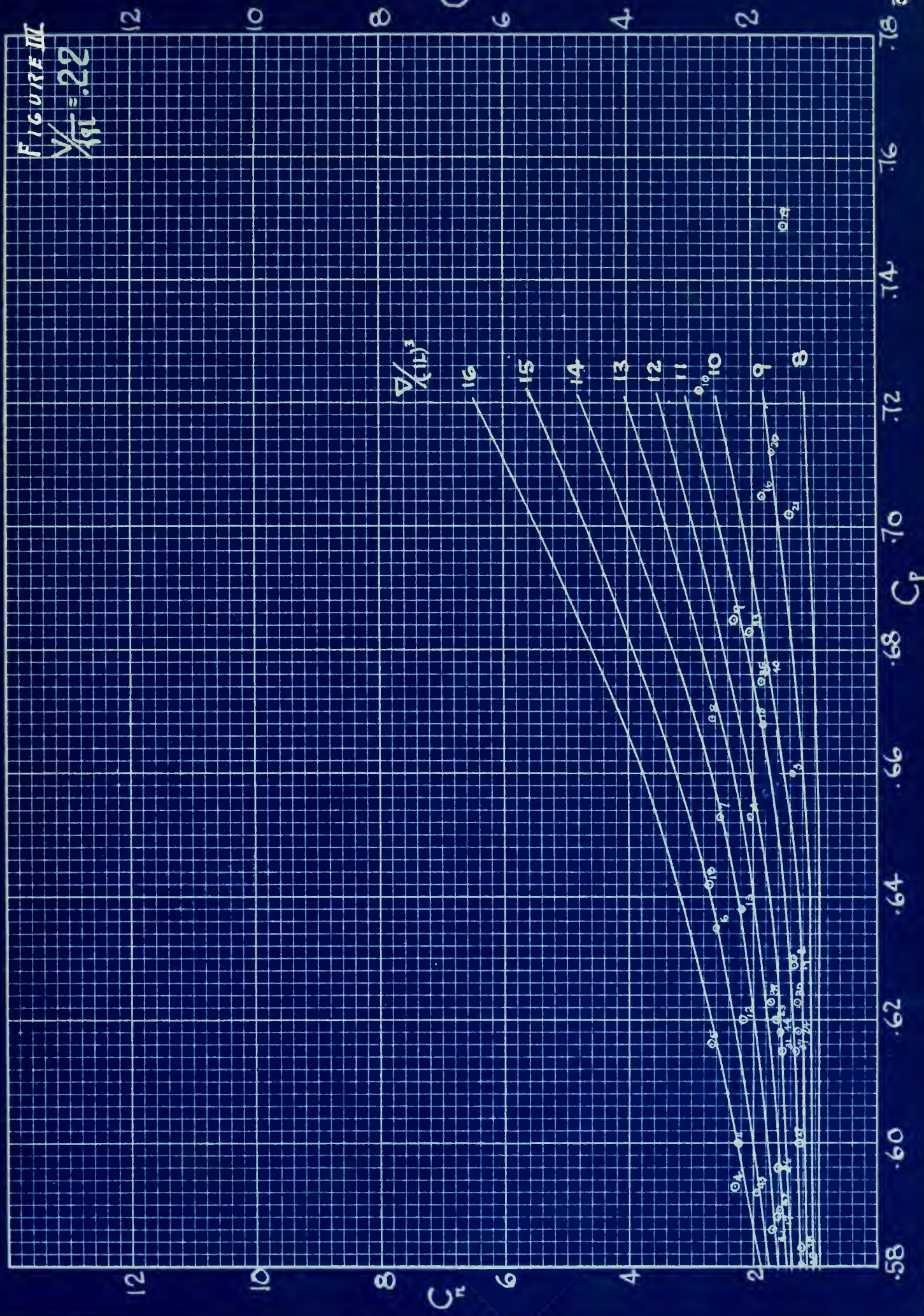


FIGURE IV

$$\frac{V}{\sqrt{gH}} = .23$$

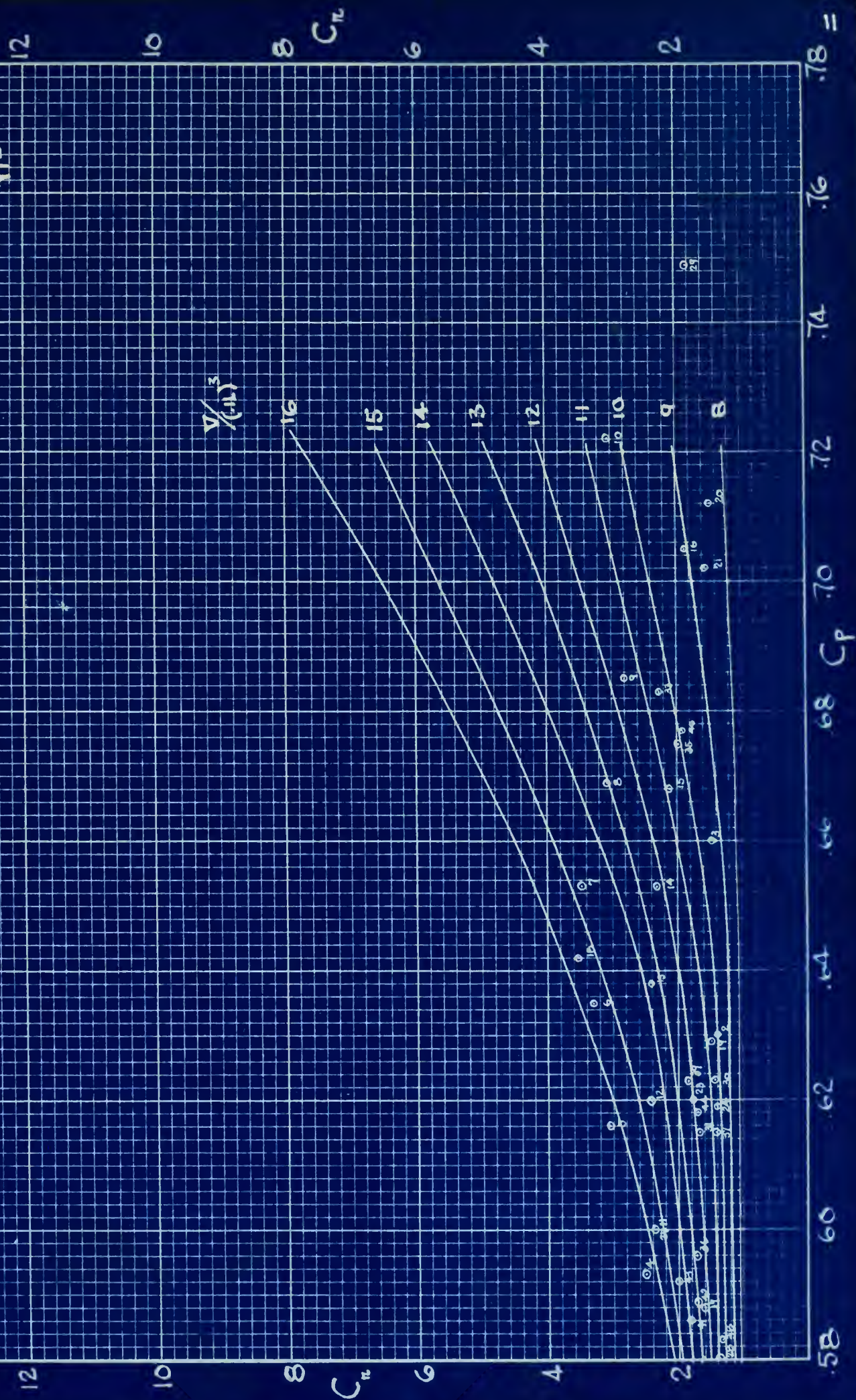


FIGURE 1
 $\frac{V}{HLE} = .24$

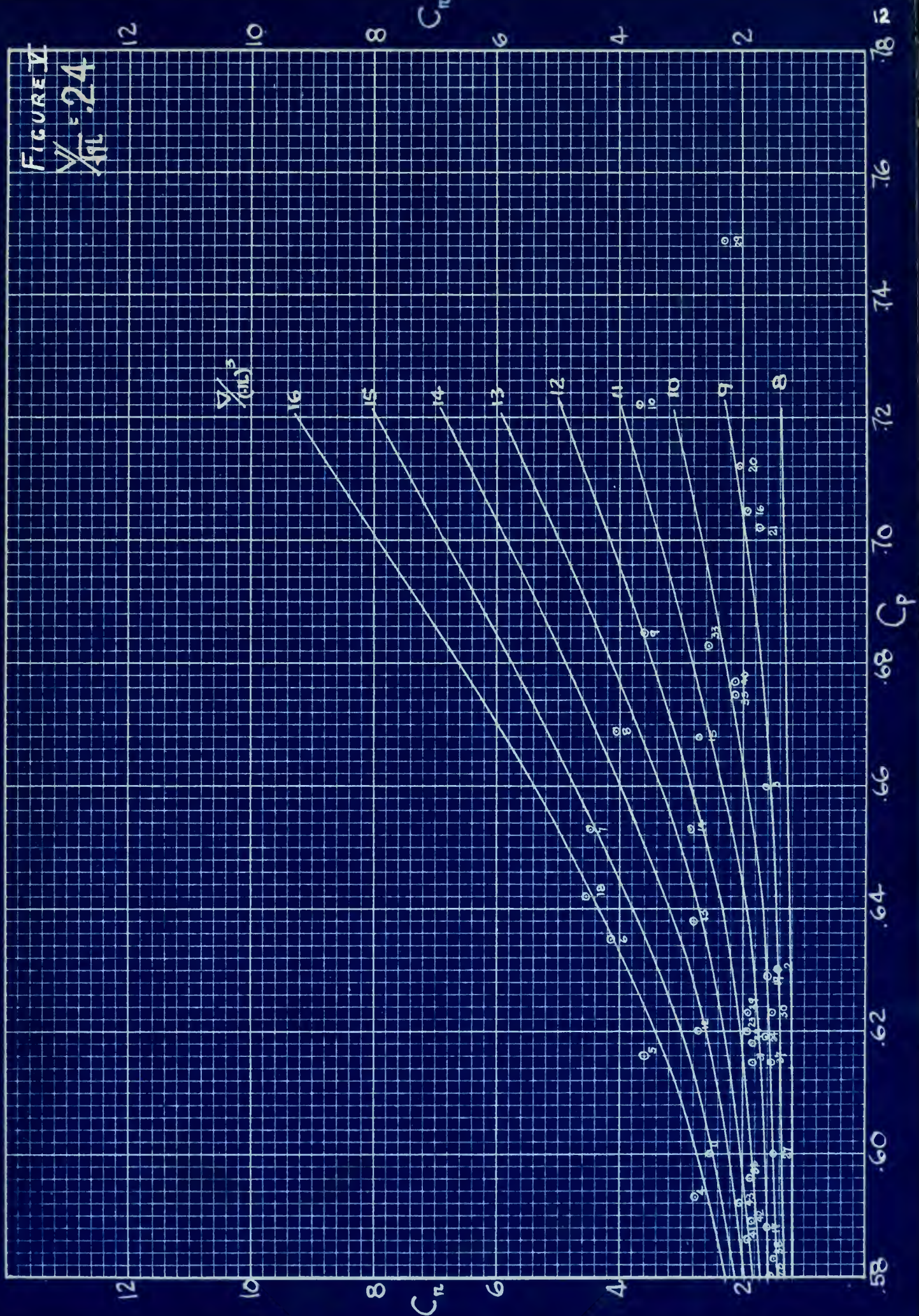


FIGURE VI

$$\frac{V}{H} = .25$$

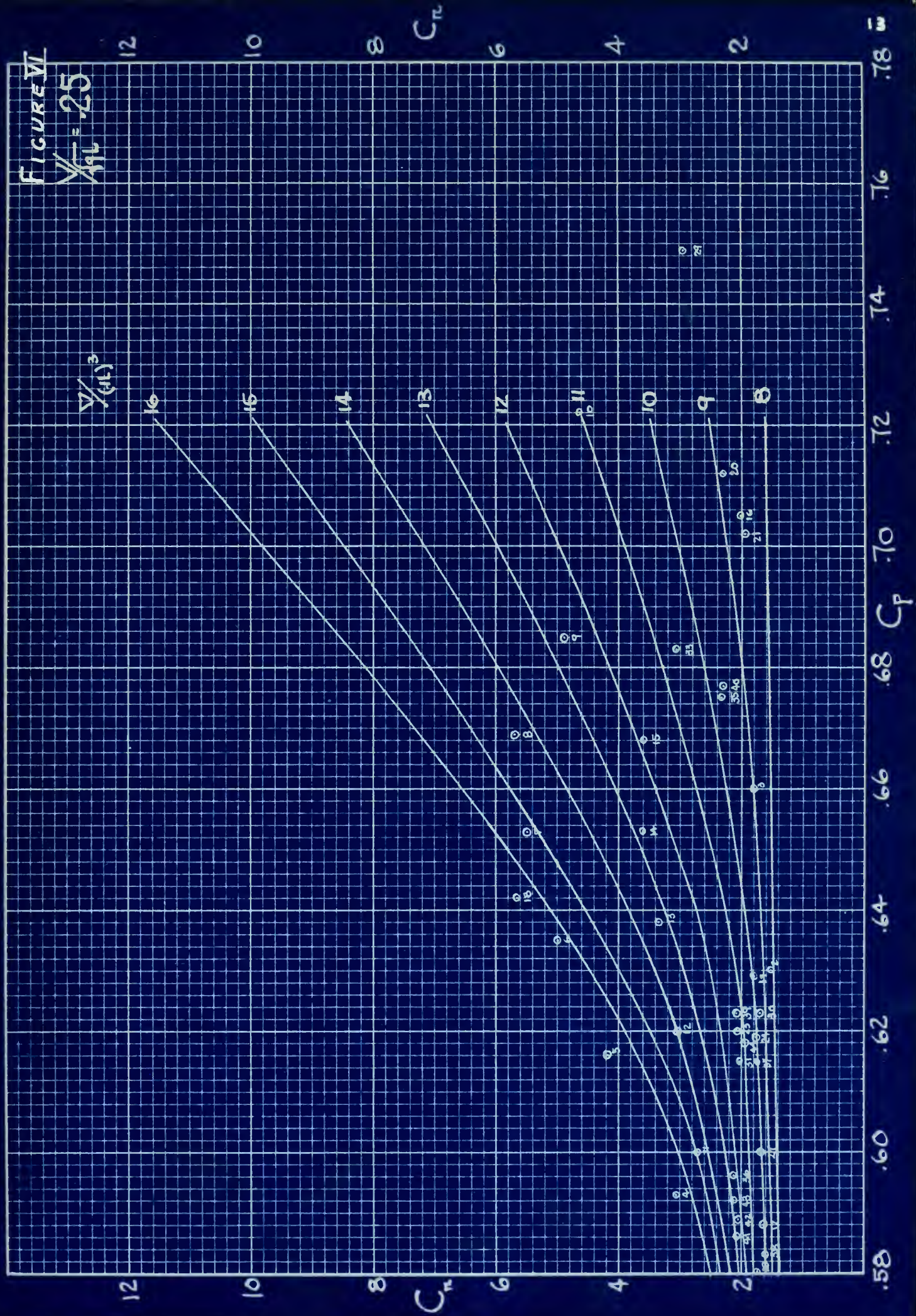


FIGURE VII
 $\frac{V}{L} = 26$

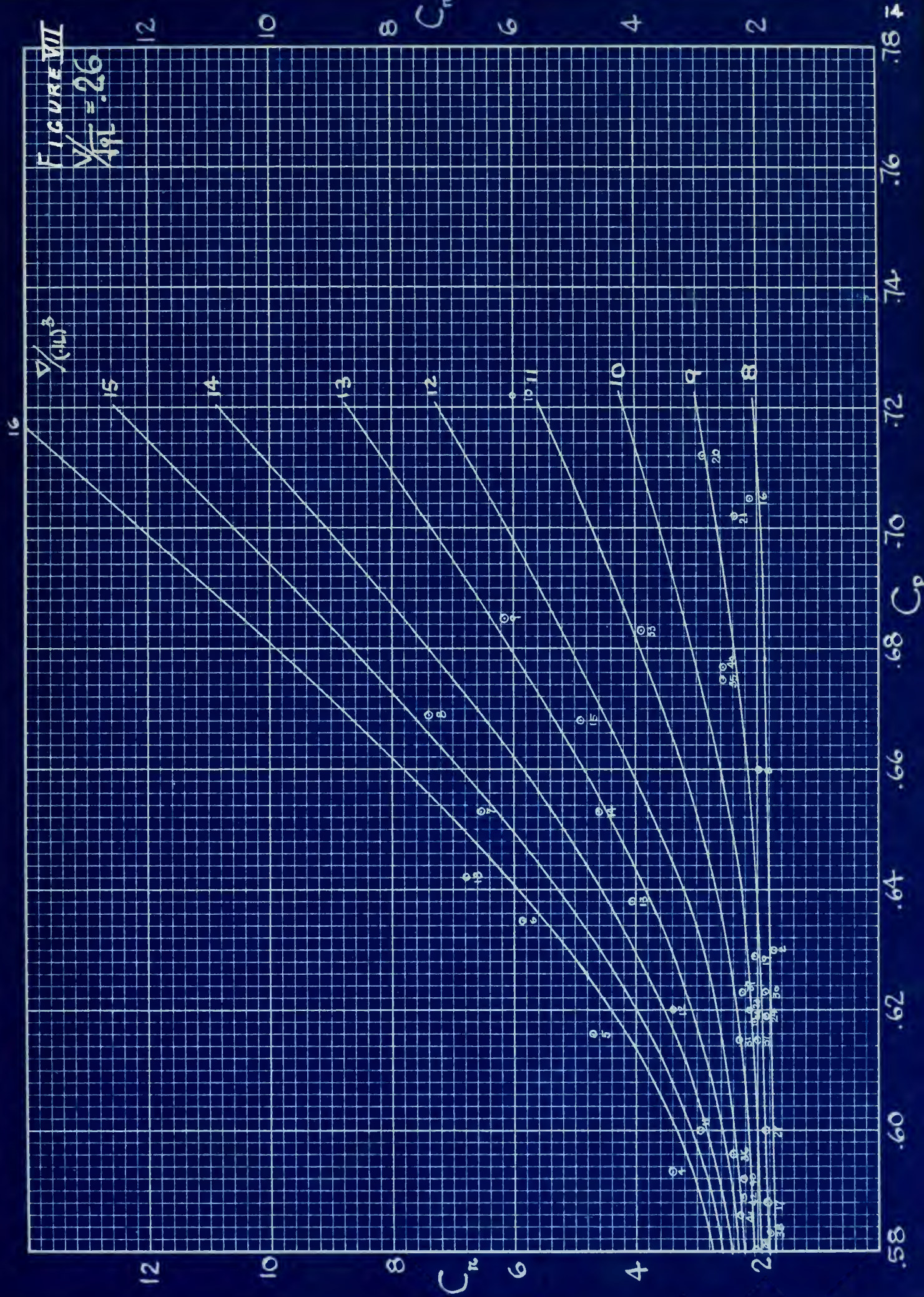
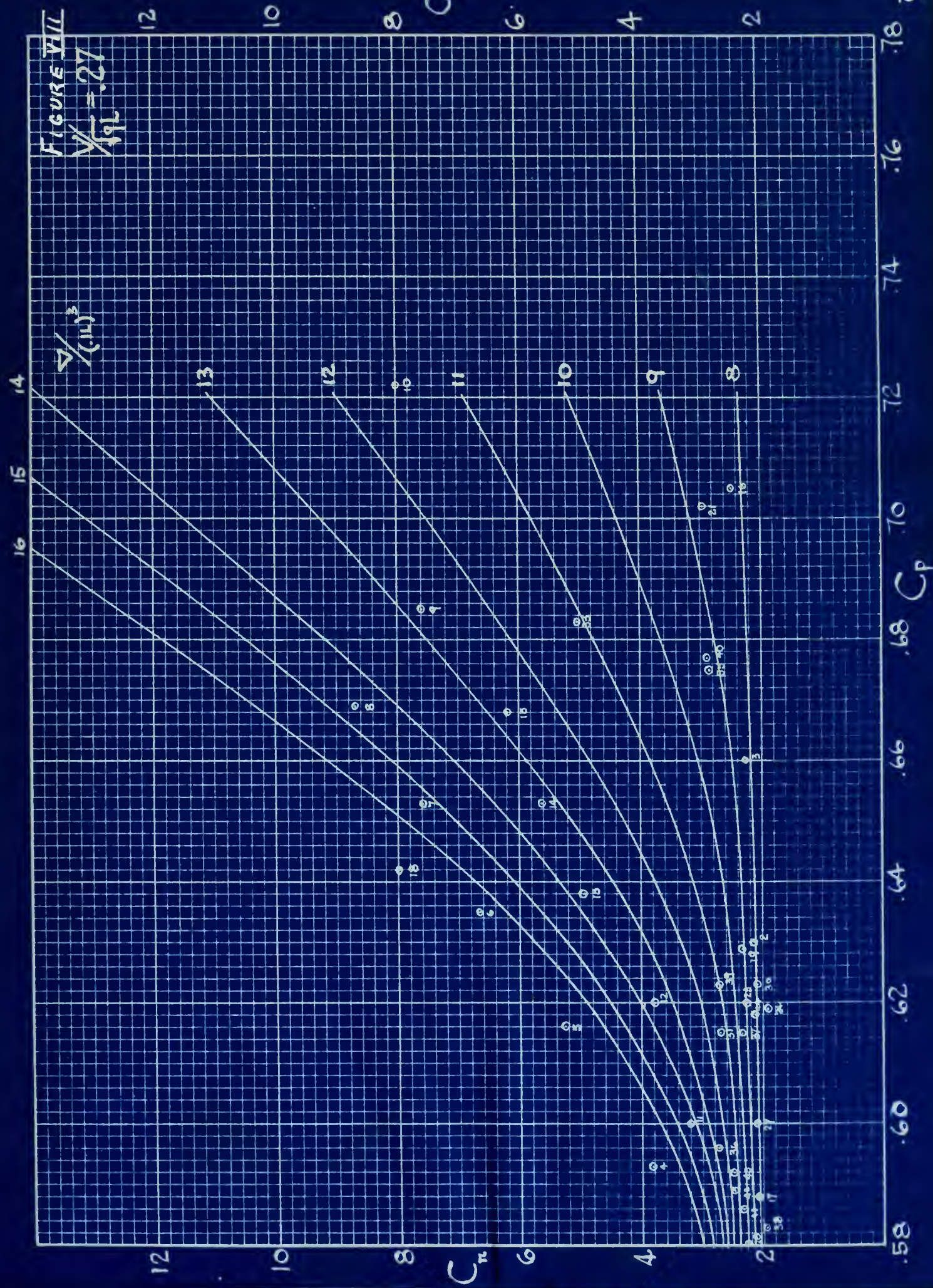


FIGURE VII

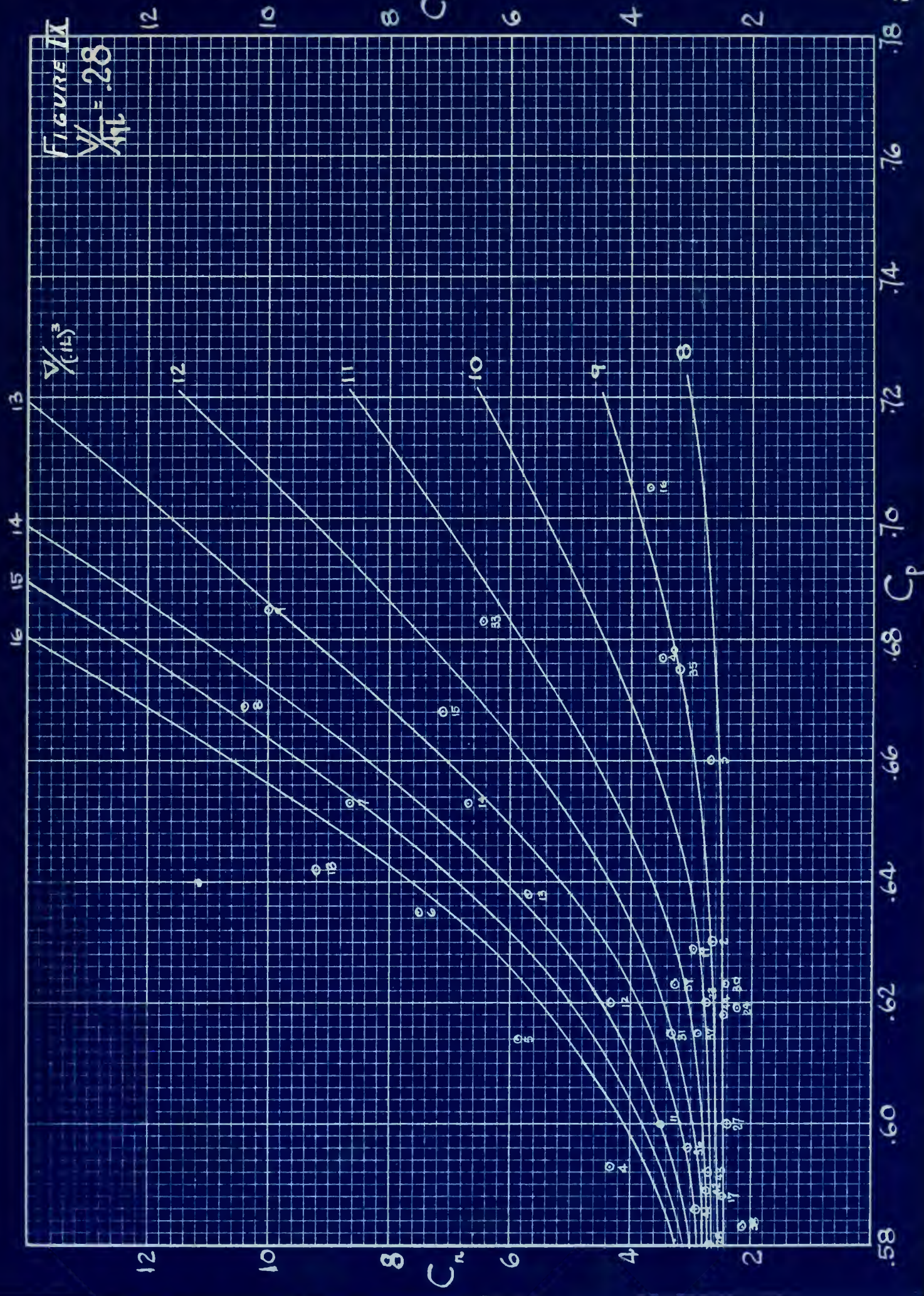
$\frac{V}{V_L} = .27$

$\frac{\Delta}{(u)^3}$



16, 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, 0

FIGURE IX
 $\frac{V}{Ht} = .28$



MADE IN U. S. A.

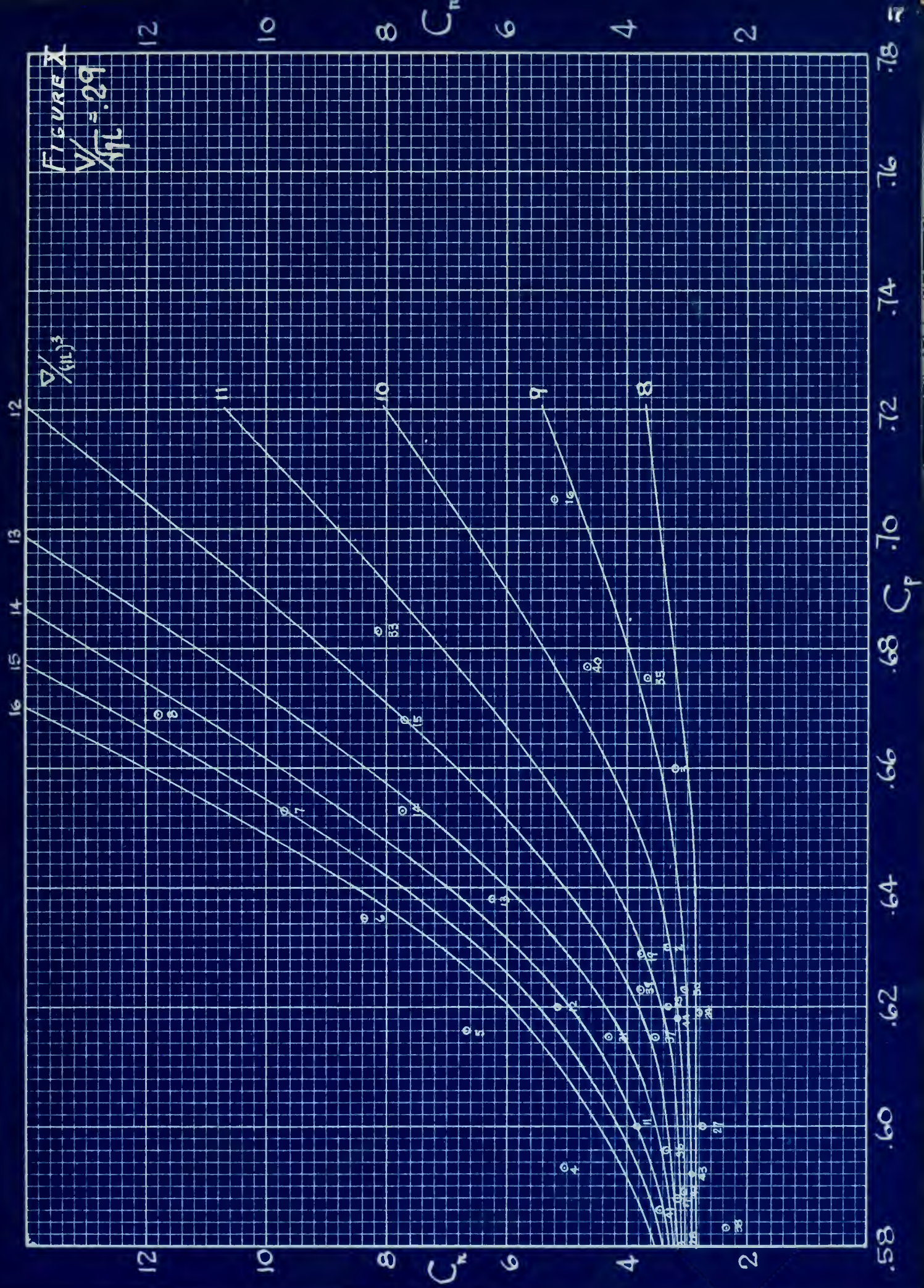


FIGURE VI
 $\frac{\Delta H}{H} = .30$

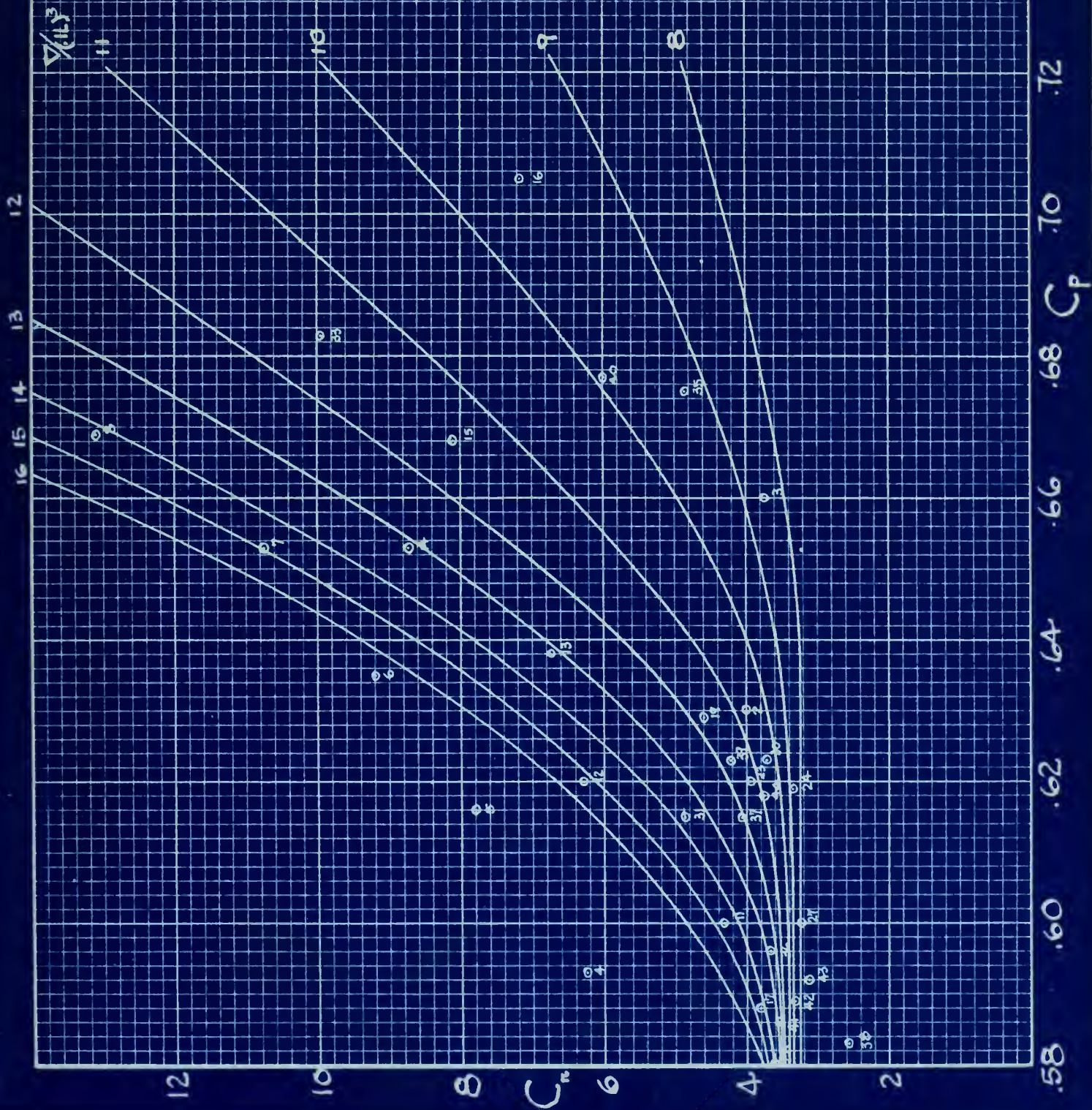
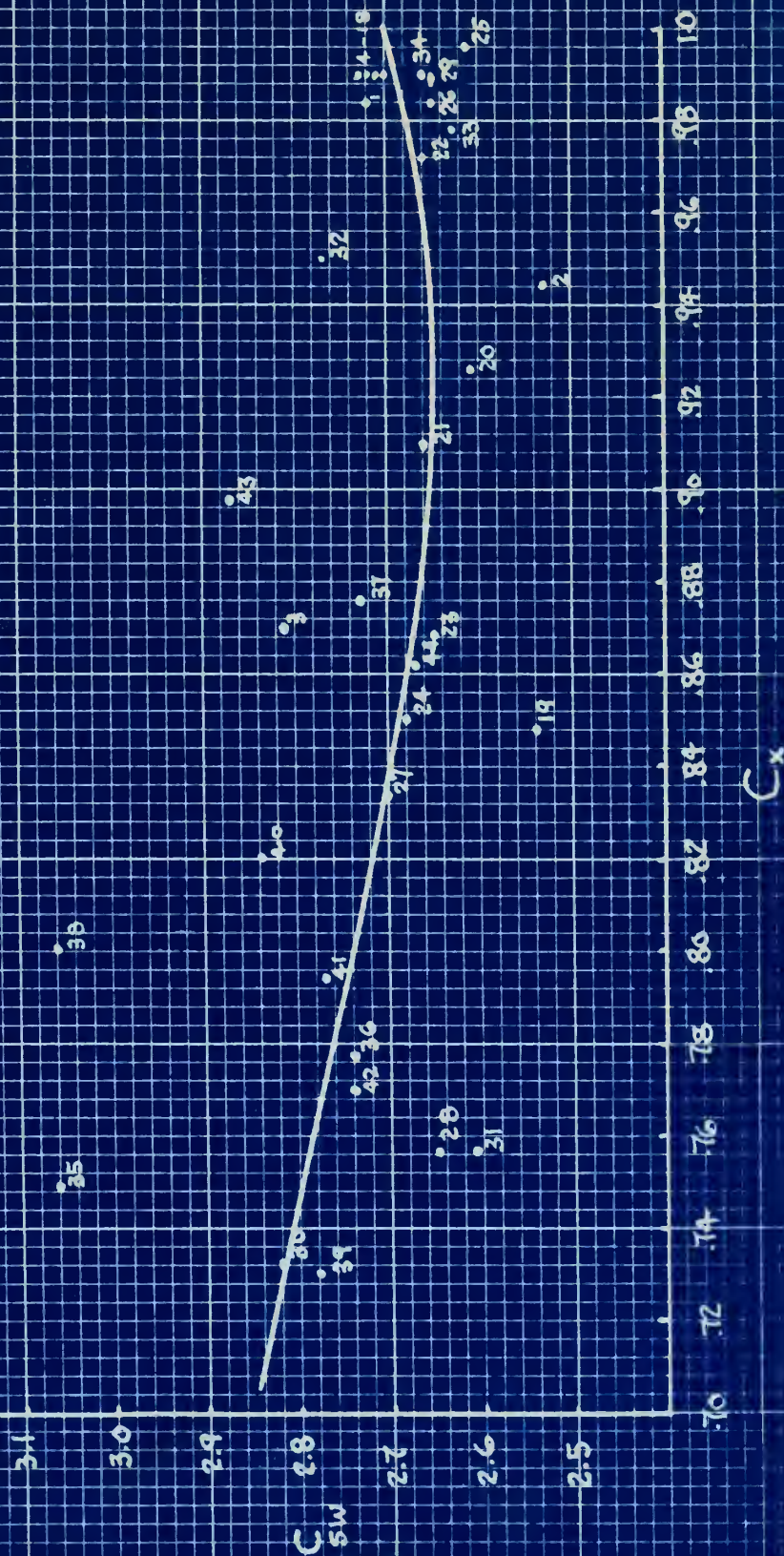


FIGURE XII

WETTED SURFACE
COEFFICIENT

$$B/H = 2.0 - 3.0$$

$$C = \frac{5}{3H} \sqrt{VL}$$



V. DISCUSSION OF RESULTS

It must be emphasized that the contours resulting from this study represent an average of the data from the 44 ship models. No particular model will have the exact resistance characteristics predicted by the contours. While individual ship resistance curves tend to have humps and hollows in them, the averaging process used in determining the contours tended to eliminate these fluctuations, although they produced what is believed to be the initial portion of a hump at Froude numbers near .30.

In order to emphasize the scattering of data, and to allow for a reexamination of the contours, the actual data has been plotted with the contours.

The study that was involved in the selection of the hull form parameters to best represent the effect of form variation on the residual resistance coefficient, indicated that none of the overall form coefficients was entirely satisfactory. Various combinations of these parameters were tried without finding any better correlation. This fact fostered the belief that the details of design, such as the arrangement of skeg, rudders, and stem had considerable influence on the resistance. In addition, it is felt that better correlation might have been attained if it had been possible to include such items as the longitudinal position of the center of buoyancy, the angle of water line entrance, and the entrance prismatic coefficient in the parameters defining the hull form.

1. INTRODUCTION

It must be emphasized that the contours resulting from this study represent an average of the data from the 11 ship models. No particular model will have the most extensive characteristics predicted by the contours. While individual ship resistance curves tend to have humps and hollows in them, the average curves used in determining the contours tended to eliminate these fluctuations, although they produced what is believed to be the initial portion of a hump at speeds between 10 and 15 knots. In order to emphasize the scattering of data, and to allow for a re-examination of the contours, the actual data was placed along with the contours.

The study that was involved in the selection of the hull form parameters to first represent the effect of hull resistance on the resistance coefficient, indicated that range of the overall form coefficient was actually satisfactory. Various combinations of these parameters were tried without leading any better correlation. This fact led to the belief that the details of design, such as the arrangement of deck, rudders, and other had considerable influence on the resistance. It was felt that better correlation might have been obtained if it had been possible to include such items as the longitudinal position of the center of buoyancy, the angle of water line entrance, and the entrance pressure coefficient in the parameter defining the hull form.

The authors compared the determined contours with a similar contour derived from Taylor's Standard Series at a volume-length ratio of 7.0. In general, there was good agreement both in shape and magnitude. At high Froude numbers, however, in the vicinity of .30, the Taylor contour tended to rise more sharply to higher values. This indicates that the Taylor contours provide a more pronounced hump in the resistance curve at Froude numbers in the vicinity of .30. The higher residual resistance coefficient values, as indicated by the Taylor contours, was not borne out by the model evidence.

A similar comparison was made between the derived contours and contours taken from the "Takagi" series. In this case, the derived contours showed a much wider variation of the residual resistance coefficient with volume-length ratio at all Froude numbers and prismatic coefficients. The best agreement occurred at the low Froude numbers. At the lowest prismatic coefficients (.58), the Takagi values were slightly higher than the determined contours for all volume-length ratio values. At the higher prismatic coefficients the Takagi values for high volume-length ratios were considerably lower, and for low volume-length ratios were slightly higher than the determined contours throughout the range of Froude number values.

The crossover area where the derived contours and the Takagi contours are in good agreement were as follows:

The authors compared the determined constants with a similar constant derived from Taylor's standard series at a volume-length ratio of 7.5. In general, there was good agreement but in some cases, at high Péclet numbers, however, in the vicinity of 10, the latter constant tended to give more rapidly increasing values. This indicates that the Taylor constant provides a more pronounced jump in the resistance curve at those numbers in the vicinity of 10. The higher resistance coefficients, however, as indicated by the Taylor constant, was not borne out by the actual values.

A similar comparison was made between the derived constants and constants from the "Taylor" series. In this case, the Taylor constant showed a much wider variation of the resistance coefficient with volume-length ratio than the Taylor constant. The best agreement occurred at the low Péclet numbers. At the highest resistance coefficients (1.50) the Taylor values were slightly higher than the determined constants for all volume-length ratio values. At the lower resistance coefficients the Taylor values for high volume-length ratios were considerably lower, and for low volume-length ratios were slightly higher than the determined constants throughout the range of Péclet number values.

The authors note that the derived constants for the Taylor series are in good agreement with the following:

<u>Cp.</u>	<u>Crossover $\nabla / (L^3)$</u>
.70	9.5
.67	10.3
.64	12
.61	14

It is felt that the determined contours better represent the average of the models studied than does the Takagi series data. This is no doubt due to the specific type of ship that formed the prototype of the Takagi series.

A third comparison was made. This comparison is between the originally calculated residual resistance coefficient curves for each model and a similar curve taken from the derived contours. These curves will be found in the Appendix of this thesis. The results of this comparison were as follows:

Twenty-four of the predictions agreed quite well with the original curves. Of these 24, 14 could be classed as completely reliable predictions. Five were predicted too high and five were predicted too low. Of the remaining models, nine were predicted considerably higher and two considerably lower than the original data indicated. Nine other models had hull form parameters that did not fall within the range for which the contours were drawn, although they were used to aid in determining the contours.

It has been proposed in many quarters that a standard series be run in this country to obtain data on the resistance characteristics of ships in the higher ranges of displacement-length ratio.

Time	Temperature
0.0	70.
0.5	78.
1.0	84.
1.5	88.

It is felt that the determined constant better represents the average of the results obtained than does the least squares value. This is no doubt due to the peculiar type of error involved in the readings of the thermocouples.

A third comparison was made. This comparison is between the originally calculated vertical resistance coefficients and for each model and a similar curve taken from the derived constants. These curves will be found in the Appendix of this report. The results of this comparison were as follows:

Twenty-four of the predictions agreed within 10% with the original curves. Of these 24, 14 could be classified as definitely reliable predictions. Five were predicted too high and five were predicted too low. Of the remaining models, nine were predicted considerably higher and two considerably lower than the original data indicated. Nine other models had full four percent error and did not fall within the range for which the curves were drawn. Although they were used to aid in determining the constants.

It has been observed in many cases that a standard error is not in this country to obtain data on the resistance coefficient of ships in the higher range of displacement-length ratio.

This study indicates that the choice of a prototype for such a series might be difficult. The type of ship to be represented seems to have considerable bearing on the problem. For example, this study indicates a tendency for tugboat types to show somewhat lower resistance in general than the average contours, whereas other types such as merchant ship forms are generally more consistent with the derived contours. These tendencies are no doubt due to details of design not represented by the selected form parameters. To get one prototype which would yield data consistent with all types seems rather unlikely.

The optimum value of prismatic coefficient with respect to minimizing the residual resistance coefficient is indicated at about a prismatic coefficient of .58. In this vicinity at all Froude numbers, the variation of residual resistance with prismatic coefficient is rather small. In addition, the contours in the vicinity of the optimum prismatic coefficient indicate a less pronounced variation of the residual resistance coefficient with changes in volume-length ratio than at higher prismatic coefficients. This location for the optimum prismatic coefficient agrees well with what might be predicted from Taylor's Standard Series.

It is believed that this study can be of value and assistance to Naval Architects in selecting hull form parameters and in predicting the resistance characteristics of new designs in the high displacement-length ratio range. In addition, it can form a basis of comparison and reference. It is hoped that the presentation is

This study indicates that the effect of a prototype for such a
series might be different. The type of ship to be represented
seems to have considerable bearing on the results. For example,
this study indicates a tendency for English speakers to show more
what more variation in general than the average speakers,
whereas other types such as merchant ships show are generally
more consistent with the desired concept. These phenomena are
no doubt due to habits of design and representation of the subject
from perspective. To get the prototype which would yield data con-
sistent with all types seems rather unlikely.

The optimal value of optimum coefficient with respect to
minimizing the residual resistance coefficient is indicated as
about a percentage coefficient of .28. In this study at all
times, however, the variation of residual resistance with pro-
peller coefficient is rather small. In addition, the variation
in the study of the optimum primary coefficient indicates
a less pronounced variation of the residual resistance coefficient
with changes in volume-fraction ratio than in higher primary co-
efficients. This location for the optimum primary coefficient
cannot well be said to be indicated from Figure 10, however.

It is believed that this study can be of value and assistance
to naval architects in indicating that low resistance and is pre-
dicting the resistance characteristics of new designs in the high
displacement-speed ratio range. In addition, it can show a basis
of comparison and reference. It is hoped that the presentation is

such that additional information and data can be added as new designs are tested, thus providing evidence for either verifying or modifying the presented contours.

VI. CONCLUSIONS

1. Average resistance characteristics of ships with displacement-length ratios above 250 and whose beam-draft ratios lie between 2 and 3 can be predicted by the contours presented.
2. The optimum value of longitudinal prismatic coefficient based on minimum residual resistance coefficient is about .58.
3. At the optimum value of longitudinal prismatic coefficient, the variation of residual resistance coefficient with displacement-length ratio is small.
4. The variation of residual resistance coefficient with displacement-length ratio increases with increase of longitudinal prismatic coefficient above the optimum.
5. The parameters used to define the model hull forms are not the only ones influencing the residual resistance characteristics of the ships. Therefore, any particular model may have resistance characteristics greatly different from those predicted by these curves solely from the fact that an important form parameter is not included in the identification of the vessel.
6. It is felt that the angle of entrance of the load waterline, and the longitudinal position of the center of buoyancy are the most significant parameters that were not available for this study.
7. It is possible to systematize "scattered data" on the resistance characteristics of ships. The results, while not as conclusive as could be derived from a standard series of model tests, do provide generalized trends which are of value.

THE PROBLEM

1. The first question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
2. The second question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
3. The third question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
4. The fourth question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
5. The fifth question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
6. The sixth question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
7. The seventh question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
8. The eighth question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
9. The ninth question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.
10. The tenth question is whether the data are sufficient to allow a comparison of the two methods. It is clear that the data are not sufficient to allow a comparison of the two methods. The data are not sufficient to allow a comparison of the two methods.

VII. RECOMMENDATIONS

1. It is recommended that a standard series type investigation be carried out for ships of high displacement-length ratios using the data that has been presented here to aid in the selection of a prototype vessel or parent form.
2. It is recommended that the data as presented here be used as a starting point for further correlation and for comparison with new designs as they are tested. To a large extent, the value of this study lies in its use for further comparisons, correlations, and additions to the systematized collection of data with a view toward improving the contours presented.
3. The contours as presented should be used with discretion in predicting the residual resistance characteristics of new designs, bearing in mind the deviation of individual models from the average contours.

RECOMMENDATIONS

1. It is recommended that the following be included in the report to be submitted to the Board of Directors of the Corporation for the year ending December 31, 1934: (a) A statement of the results of the operations of the Corporation for the year ending December 31, 1934; (b) A statement of the financial condition of the Corporation as of December 31, 1934; (c) A statement of the assets and liabilities of the Corporation as of December 31, 1934; (d) A statement of the income and expenses of the Corporation for the year ending December 31, 1934; (e) A statement of the dividends paid to the stockholders of the Corporation for the year ending December 31, 1934; (f) A statement of the salaries and wages paid to the officers and employees of the Corporation for the year ending December 31, 1934; (g) A statement of the interest paid on the indebtedness of the Corporation for the year ending December 31, 1934; (h) A statement of the taxes paid by the Corporation for the year ending December 31, 1934; (i) A statement of the other items which may be required by the Board of Directors of the Corporation.

2. It is recommended that the following be included in the report to be submitted to the Board of Directors of the Corporation for the year ending December 31, 1935: (a) A statement of the results of the operations of the Corporation for the year ending December 31, 1935; (b) A statement of the financial condition of the Corporation as of December 31, 1935; (c) A statement of the assets and liabilities of the Corporation as of December 31, 1935; (d) A statement of the income and expenses of the Corporation for the year ending December 31, 1935; (e) A statement of the dividends paid to the stockholders of the Corporation for the year ending December 31, 1935; (f) A statement of the salaries and wages paid to the officers and employees of the Corporation for the year ending December 31, 1935; (g) A statement of the interest paid on the indebtedness of the Corporation for the year ending December 31, 1935; (h) A statement of the taxes paid by the Corporation for the year ending December 31, 1935; (i) A statement of the other items which may be required by the Board of Directors of the Corporation.

3. The Board of Directors of the Corporation is recommended to cause to be prepared and submitted to the stockholders of the Corporation at the annual meeting of the Corporation for the year ending December 31, 1934, a report of the Board of Directors of the Corporation for the year ending December 31, 1934, containing the following information: (a) A statement of the results of the operations of the Corporation for the year ending December 31, 1934; (b) A statement of the financial condition of the Corporation as of December 31, 1934; (c) A statement of the assets and liabilities of the Corporation as of December 31, 1934; (d) A statement of the income and expenses of the Corporation for the year ending December 31, 1934; (e) A statement of the dividends paid to the stockholders of the Corporation for the year ending December 31, 1934; (f) A statement of the salaries and wages paid to the officers and employees of the Corporation for the year ending December 31, 1934; (g) A statement of the interest paid on the indebtedness of the Corporation for the year ending December 31, 1934; (h) A statement of the taxes paid by the Corporation for the year ending December 31, 1934; (i) A statement of the other items which may be required by the Board of Directors of the Corporation.

4. It is recommended that the following be included in the report to be submitted to the Board of Directors of the Corporation for the year ending December 31, 1936: (a) A statement of the results of the operations of the Corporation for the year ending December 31, 1936; (b) A statement of the financial condition of the Corporation as of December 31, 1936; (c) A statement of the assets and liabilities of the Corporation as of December 31, 1936; (d) A statement of the income and expenses of the Corporation for the year ending December 31, 1936; (e) A statement of the dividends paid to the stockholders of the Corporation for the year ending December 31, 1936; (f) A statement of the salaries and wages paid to the officers and employees of the Corporation for the year ending December 31, 1936; (g) A statement of the interest paid on the indebtedness of the Corporation for the year ending December 31, 1936; (h) A statement of the taxes paid by the Corporation for the year ending December 31, 1936; (i) A statement of the other items which may be required by the Board of Directors of the Corporation.

VIII. APPENDIX

Appendix (A)

Supplementary Introduction

The index of the models whose resistance data was used in this study is included, believing that it will be of value in any further analysis of the presented contours. It contains most of the hull form parameters that might be of use together with a brief description of the type of vessel and the Taylor Model Basin model number associated with the model.

Appendix (D) is a sample calculation sheet for calculating the residual resistance coefficients, Froude numbers, C and K values. This form was taken from the publication listed in the Bibliography as item [6] and Taylor Model Basin calculation form Number 71.

Appendix (E) contains the original model test data from which the residual resistance coefficient, Froude numbers, C and K values were calculated, together with the residual resistance coefficient curve, both as calculated from the original model test data and as determined from the contours for each model. Curves of C versus K are also included for each model, believing that they may be of value in judging the merits of particular ships.

Appendix (F) is the Bibliography of the thesis.

Appendix A

Geometrical Interpretation

The index of the vector space V is defined as the dimension of the space V . This index is invariant under linear transformations of V . If V is a vector space of dimension n , then the index of V is n . The index of V is also equal to the rank of the matrix A of the linear transformation T of V into V . The index of V is also equal to the rank of the matrix A of the linear transformation T of V into V .

Proposition (1) is a special case of the following theorem. Let V be a vector space of dimension n . Let T be a linear transformation of V into V . Let A be the matrix of T relative to a basis of V . Let r be the rank of A . Then the index of V is r . This theorem is also known as the Rank-Nullity Theorem.

Proof. VI.

Proposition (2) states that the index of V is equal to the rank of the matrix A of the linear transformation T of V into V . This is a special case of the following theorem. Let V be a vector space of dimension n . Let T be a linear transformation of V into V . Let A be the matrix of T relative to a basis of V . Let r be the rank of A . Then the index of V is r . This theorem is also known as the Rank-Nullity Theorem.

Proposition (3) is the Rank-Nullity Theorem.

Appendix (B)Symbols

L	Length	—	feet
B	Beam	—	feet
H	Draft	—	feet
Δ	Displacement-pounds or tons		
∇	Volume of displacement	—	cubic feet
S	Wetted Surface	—	square feet
ρ	Mass density of water	—	pound sec ² /feet ⁴
ν	Kinematic Viscosity	—	ft ² /sec
V	Velocity	—	feet per second
V_k	Velocity	—	knots
Re	Reynolds number	VL/ν	(nondimensional)
$V/\sqrt{gL}$	Froude number		(nondimensional)
R_T	Total Resistance	—	pounds
R_F	Frictional Resistance	—	pounds
R_R	Residual Resistance	—	pounds
C_T	Total Resistance Coefficient	$R_T / \frac{1}{2} \rho SV^2$	(nondimensional)
C_F	Frictional Resistance Coefficient	$R_F / \frac{1}{2} \rho SV^2$	(nondimensional)
C_R	Residual Resistance Coefficient	$R_R / \frac{1}{2} \rho SV^2$	(nondimensional)

(C) 400 foot ship = $\frac{427.1}{\Delta^{2/3} V_k^3} \cdot \frac{1/2 \rho SV_k^3 C_T (1.689)^3}{550} =$

$$\frac{427.1 \text{ EHP}_T}{\Delta^{2/3} V_k^3}$$

Appendix

Table	
1	Length - feet
2	Area - sq ft
3	Volume - cu ft
4	Displacement - pounds of water
5	Volume of displacement - cubic feet
6	Weight of water - pounds
7	Weight of water - pounds
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98	Weight of water - pounds
99	Weight of water - pounds
100	Weight of water - pounds

$$\frac{100 \times 1.025}{1.025}$$

$$\textcircled{K} \quad 400 \text{ foot ship} = \frac{.5834 V_k}{\Delta^{1/6}}$$

HP_T Total Effective Horsepower — horsepower

$\nabla/(\Delta L)^3$ Volume length ratio (nondimensional)

$\Delta/(1/100)^3$ Displacement-length ratio Tons (saltwater 59°F)/ft³

C_p Longitudinal prismatic coefficient $\nabla/\text{Midship section area} \times L$
(nondimensional)

C_b Block Coefficient ∇/LBH

C_x Midship Section Coefficient $\frac{\text{Midship Section Area}}{BH}$ (nondimensional)

C_{PV} Vertical Prismatic Coefficient $\nabla/\text{Waterplane Area} \times H$

C_W Waterplane Coefficient $\frac{\text{Waterplane Area}}{L \times B}$

C_{SW} Wetted Surface Coefficient $S/\sqrt{\Delta L}$

' Prize refers to 400 foot ship

② The test was a $\frac{1}{2}$ inch

total thickness inspection - inspection
of the joints (see drawing)

③ The test was a $\frac{1}{2}$ inch

total thickness inspection - inspection
of the joints (see drawing)

④ The test was a $\frac{1}{2}$ inch

total thickness inspection - inspection
of the joints (see drawing)

⑤ The test was a $\frac{1}{2}$ inch

total thickness inspection - inspection
of the joints (see drawing)

⑥ The test was a $\frac{1}{2}$ inch

total thickness inspection - inspection
of the joints (see drawing)

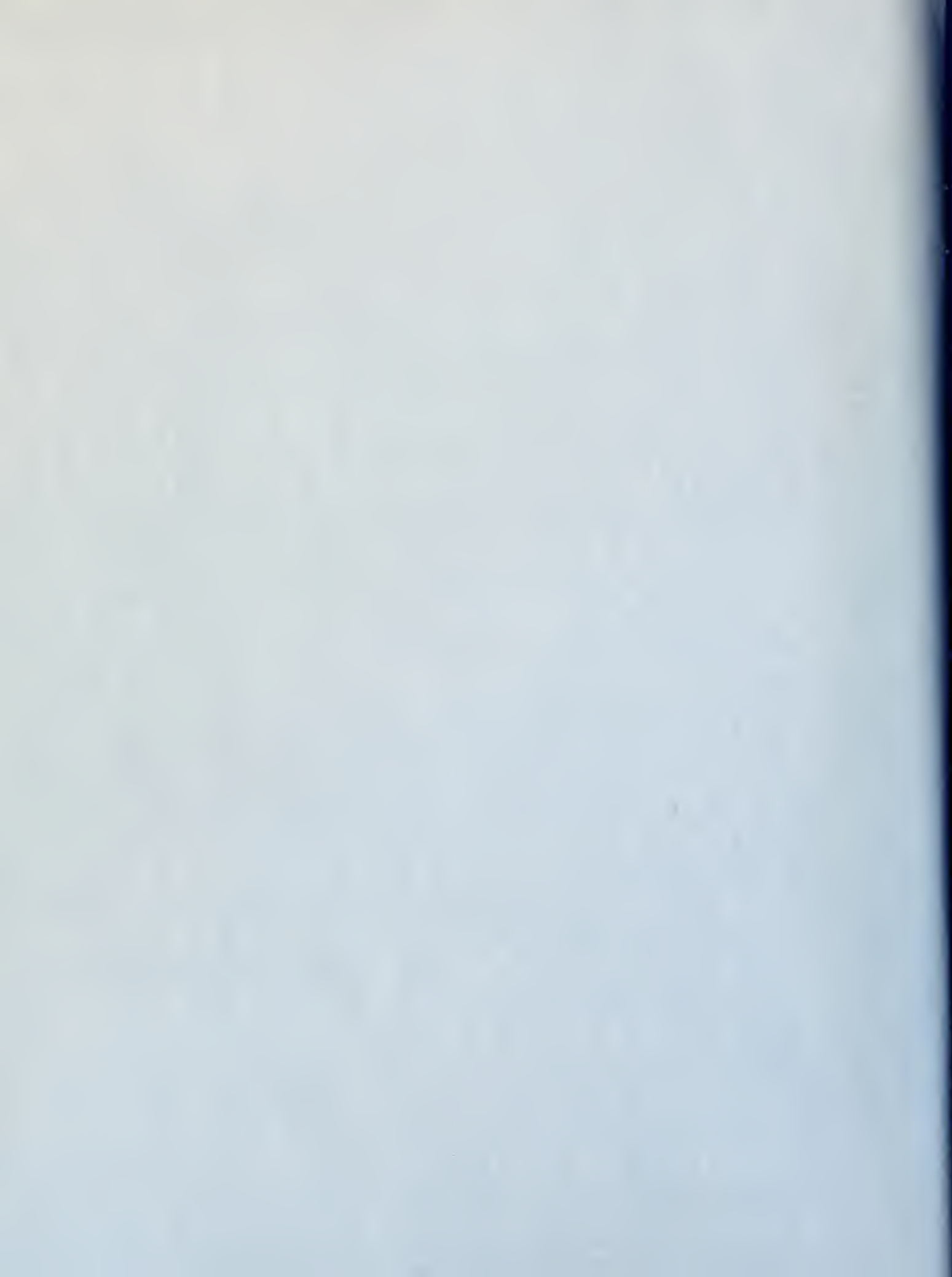
Appendix (O)

Index of Models

TABLE I

INDEX OF MODELS

SERIAL NO.	MODEL NO.	$\frac{D}{L}(\frac{1}{100})^3$	$\frac{V}{(L)}^3$	C_p	C_x	C_b	C_{pv}	C_w	C_{sw}	L/B	B/H	REMARKS
1	2433	305.0	10.70	.800	.984	.787	.890	.890	2.72	5.58	2.36	SINGLE SCREEN SUCTION DREDGE
2	2646	258.0	8.98	.632	.945	.604	.838	.721	2.53	5.09	2.59	SINGLE SCREEN ICE BREAKER
3	2834	261.0	9.10	.659	.871	.573	.747	.768	2.82	4.54	3.00	SURVEY SHIP
4	3064	549.0	19.20	.593	.990	.588			2.72	3.50	2.50	SERIES 53 (4-1-0)
5	3064	511.0	17.90	.616	.990	.611			2.72	3.70	2.50	SERIES 53 (4-1-5)
6	3064	475.0	16.65	.635	.990	.631			2.72	3.90	2.50	SERIES 53 (4-1-1)
7	3064	440.0	15.40	.653	.990	.659			2.70	4.10	2.50	SERIES 53 (4-1-1.5)
8	3064	411.0	14.37	.669	.990	.664			2.71	4.30	2.50	SERIES 53 (4-1-2)
9	3064	382.0	13.38	.685	.990	.678			2.71	4.50	2.50	SERIES 53 (4-1-2.5)
10	3064	315.0	11.08	.722	.990	.716			2.71	5.10	2.50	SERIES 53 (4-1-4)
11	3065	424.0	14.82	.600	.990	.595			2.70	4.00	2.50	SERIES 53 (5-1-0)
12	3065	397.0	13.90	.620	.990	.614			2.70	4.20	2.50	SERIES 53 (5-1-5)
13	3065	374.0	13.10	.638	.990	.632			2.70	4.40	2.50	SERIES 53 (5-1-1)
14	3065	350.0	12.25	.653	.990	.647			2.70	4.60	2.50	SERIES 53 (5-1-1.5)
15	3065	327.0	11.44	.668	.990	.661			2.73	4.80	2.50	SERIES 53 (5-1-2)
16	3065	274.0	9.57	.705	.990	.700			2.70	5.40	2.50	SERIES 53 (5-1-3.5)
17	3068	277.0	9.69	.588	.990	.584			2.72	4.90	2.50	SERIES 53 (2-2-1)
18	3070	344.0	12.06	.642	.990	.637			2.71	4.60	2.50	SERIES 53 (4-2-1.5)
19	3102	293.0	10.25	.629	.848	.534			2.54	4.18	2.99	COAST GUARD CUTTER
20	3121A	316.0	11.08	.712	.926	.660			2.61	5.34	2.09	FREIGHT PASSENGER SHIP
21	3121B	258.0	9.01	.702	.910	.639			2.64	5.22	2.61	FREIGHT PASSENGER SHIP
22	3132	281.0	9.82	.807	.912	.784	.880	.920	2.66	5.99	2.22	DREDGE
23	3138A	380.0	13.30	.620	.868	.540	.700	.770	2.65	4.29	2.21	HARBOR TUG
24	3138B	345.0	12.10	.619	.850	.524			2.68	4.15	2.54	HARBOR TUG



INDEX OF MODELS

SERIAL No	MODEL No	Δ/λ^3	∇/λ^3	C_p	C_x	C_b	C_{pv}	C_w	C_{sw}	L/B	B/H	REMARKS
25	3175	276.5	9.63	.778	.996	.774	.892	.865	2.61	5.36	2.80	HOPPER DREDGE
26	3472	272.0	9.65	.788	.984	.775	.919	.842	2.65	5.36	2.80	HOPPER DREDGE
27	3486	378.0	13.20	.600	.834	.498	.676	.737	2.70	4.18	2.15	TUG
28	3498	265.8	9.29	.580	.757	.438	.602	.726	2.69	4.24	2.63	HARBOR CUTTER
29	3685	246.6	8.62	.749	.989	.741	.908	.814	2.65	6.04	2.35	
30	3703	274.0	9.59	.623	.859	.535	.686	.779	2.82	4.80	2.42	TUG
31	3705	341.5	11.94	.615	.758	.467	.508	.725	2.61	4.06	2.38	COAST GUARD CUTTER
32	3714	259.0	9.05	.822	.950	.781			2.77		2.12	CONCRETE TANKER BARGE
33	3725	254.5	8.90	.683	.978	.668	.901	.739	2.63	5.30	2.68	FUEL OIL BARGE
34	3745	245.5	8.56	.770	.990	.762	.913	.832	2.66	6.58	2.06	CONCRETE BARGE
35	3755	243.0	8.50	.675	.749	.505	.636	.793	3.06	4.66	2.72	COSTAL MINE SWEEP
36	4085	285.5	10.00	.596	.757	.451	.622	.738	2.75	4.08	2.73	TUG
37	4086	350.0	12.23	.615	.876	.538	.711	.758	2.73	4.24	2.44	TUG
38	4087	434.0	15.17	.583	.801	.467	.626	.745	3.06	3.27	2.88	TUG
39	4088	481.5	16.89	.623	.873	.544	.701	.776	2.78	3.72	2.34	TUG
40	4090	294.0	10.30	.677	.821	.556	.717	.776	2.84	4.47	2.71	TUG
41	4091	347.0	12.15	.586	.794	.465	.648	.717	2.77	3.81	2.67	TUG
42	4093	393.0	13.75	.589	.770	.453	.611	.742	2.74	3.62	2.52	TUG
43	4094	462.0	16.18	.592	.898	.531	.713	.745	2.87	3.65	2.47	TUG
44	3138c	364.0	12.74	.618	.862	.532	.695	.766	2.67	4.22	2.36	TUG

Appendix (D)

Sample Calculation Sheet

(b) attempt

United States District Court

TABLE II
- SAMPLE CALCULATION -

Model No: 4085

APPENDAGES: RUDDER

TYPE: TUG

TEST DATE: JULY 1949

SERIAL No: 36

MODEL RANGE				λ = 36 λ' = 1297 λ'' = 46600 λ''' = 6				400' SHIP RANGE						
$\frac{1.689L}{D} = 1.85 \times 10^6$ (1) $\frac{1.689}{f \cdot g L} = .0894$ (2) $\alpha = 93.5$ (3)				$\frac{D}{(V_{100})^2} = 2855$ $\frac{D}{(V_{10})^3} = 10.0$ $C_p = .596$ $C_{R1} = .767$ $C_{R2} = .451$ $C_{R3} = .622$ $C_{W1} = .738$ $C_{W2} = 2.75$ $L/B = 4.08$ $B/H = 2.73$				$L' = 400'$ $\Delta' = 18,720 T$ $S' = 43,800 d$ $TEMP = 84^\circ F$ $\rho = 1.9905 \frac{lb}{ft^3}$ $\mu = 1.2817 \times 10^{-5} \frac{lb}{ft \cdot sec}$ $\Delta C_f = .0004$ $A' = 382$ $\Delta'^{1/2} = 5.12$ $\Delta'^{1/3} = 692.4$ $\frac{.5834}{\Delta'^{1/2}} = .1136$ $\frac{427.1 A'}{\Delta'^{1/3}} = 235.5$						
V _k	R _r	α V _k ²	V _k ²	Re	C _t	C _R	V _k /f _g L	C _R	C _t	C _{R100}	C _t	V _k '	(K)	(C)
1.00	.45	93.5	1.00	1.85 × 10 ⁶	4.78 × 10 ⁻³	.85 × 10 ³	.0894	1.00 × 10 ⁻³	1.916 × 10 ⁻³	2.316 × 10 ⁻³	3.316 × 10 ⁻³	3.36	.382	.782
1.50	.99	210.5	2.25	2.78	4.71	3.65	.1341	1.00	1.748	2.148	3.148	6.72	.763	.744
1.75	1.35	286.0	3.06	3.24	4.71	3.55	.1565	1.12	1.657	2.057	3.177	10.06	1.141	.750
2.00	1.77	374.0	4.00	3.70	4.74	3.47	.1789	1.42	1.597	1.997	3.417	13.41	1.522	.806
2.25	2.28	473.0	5.07	4.16	4.82	3.40	.2012	2.09	1.554	1.954	4.044	16.77	1.903	.954
2.50	2.90	585.0	6.25	4.62	4.97	3.34	.2237	3.66	1.520	1.920	5.580	20.15	2.285	1.317
2.75	3.22	706.0	7.56	5.09	5.25	3.28	.2460	5.46	1.492	1.892	7.292	23.50	2.665	1.718
3.00	4.91	841.0	9.00	5.55	5.84	3.24	.2685	10.50	1.467	1.867	12.367	26.85	3.050	2.920
3.25	6.44	988.0	10.57	6.01	6.52	3.19	.2905	1. REVNOLOS No: $\frac{1.689 V_k L}{D}$					5. (K) = $\frac{.5834}{\Delta'^{1/2}} V_k'$	
3.50	8.29	1143.0	12.25	6.48	7.25	3.15	.3130	2. FROUDE No: $\frac{1.689 V_k}{f \cdot g L}$					6. (C) = $\frac{427.1}{\Delta'^{1/3}} \frac{EHP' \cdot 427.1 A' C_t'}{\Delta'^{1/3}}$	
3.75	10.50	1316.0	14.07	6.94	7.99	3.12	.3355	3. C _t = $\frac{R_t}{\frac{1}{2} \rho S (1.689 V_k)^2} = \frac{R_t}{\alpha V_k^2}$					7. C _R = C _k - C _f	
4.00	13.25	1497.0	16.00	7.40	8.85	3.08	.3580	α = 1.426 ρ S					8. $\frac{.242}{\sqrt{C_f}} = \log_{10} (Re C_f)$	
4.10	15.01	1571.0	16.80	7.59	9.55	3.07	.3670	4. EHP _t = $\frac{1}{2} \rho S (1.689 V_k)^3 C_t = AV_k^3 C_t$						
4.20	17.05	1650.0	17.63	7.77	10.34	3.06	.3760							
4.30	19.50	1730.0	18.50	7.95	11.29	3.05	.3845							
4.40	22.65	1810.0	19.37	8.14	12.52	3.03	.3935							
4.50	26.80	1892.0	20.25	8.32	14.14	3.02	.4030							



Appendix (E)

Curves of Residual Resistance Coefficient vs.
Froude Numbers, both Calculated and as Predicted
from the Contours. Curves of © vs. ®.

Original Model Test Data

Volume 12

Index of British Periodicals 1811-1812
Index of British Periodicals 1813-1814
Index of British Periodicals 1815-1816
Index of British Periodicals 1817-1818
Index of British Periodicals 1819-1820

FIGURE XIV

MODEL No: 2646

SERIAL No 2

$L = 14.0'$
 $B = 2.748'$
 $H = 1.059' \text{ EK}$
 $\Delta = 1538.5$
 $S = 47.156$
 $L/B = 5.09$
 $B/H = 2.59$
 $C_p = .632$
 $V_{LIP} = 8.98$
 $C_k = .945$
 $C_B = .604$
 $C_{PV} = .838$
 $C_W = .721$
 $C_{SW} = 2.53$

MODEL DATA

TEMP = 59°F

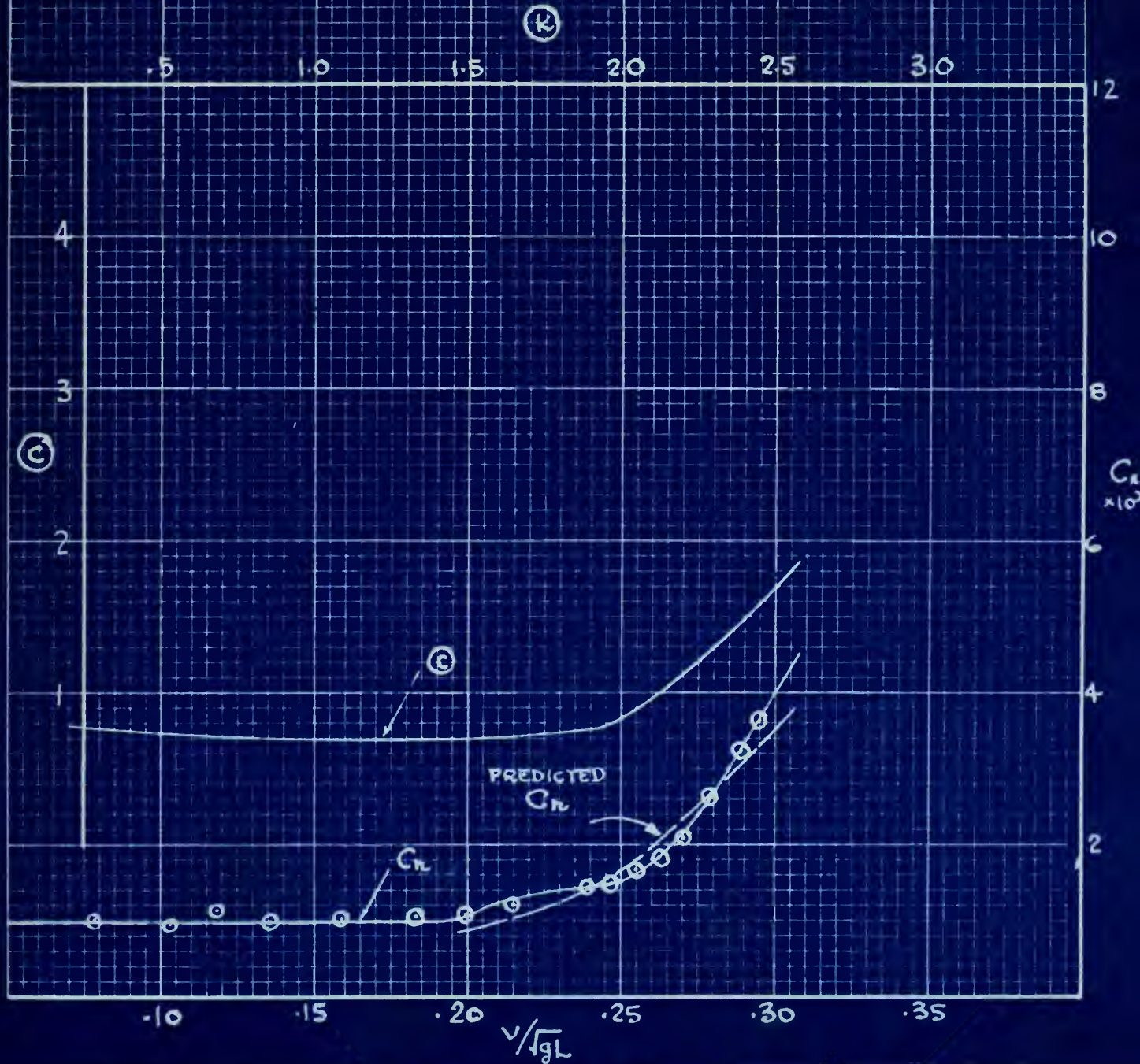
V_k	R_T
1.0	.64
1.1	1.03
1.2	1.25
1.3	1.70
1.4	2.33
1.5	3.02
1.6	3.54
1.7	4.28
1.8	5.40
1.9	6.88
2.0	8.70
2.1	10.3
2.2	11.88
2.3	14.15
2.4	16.66
2.5	19.00

APPENDAGES: RUDDER & STERN FRAME
 TYPE: ICE BREAKER (C.G.)
 SINGLE SCREW.

© vs (K) FOR 400' SHIP

$\Delta C_S = .0004$

TEMP = 59°F



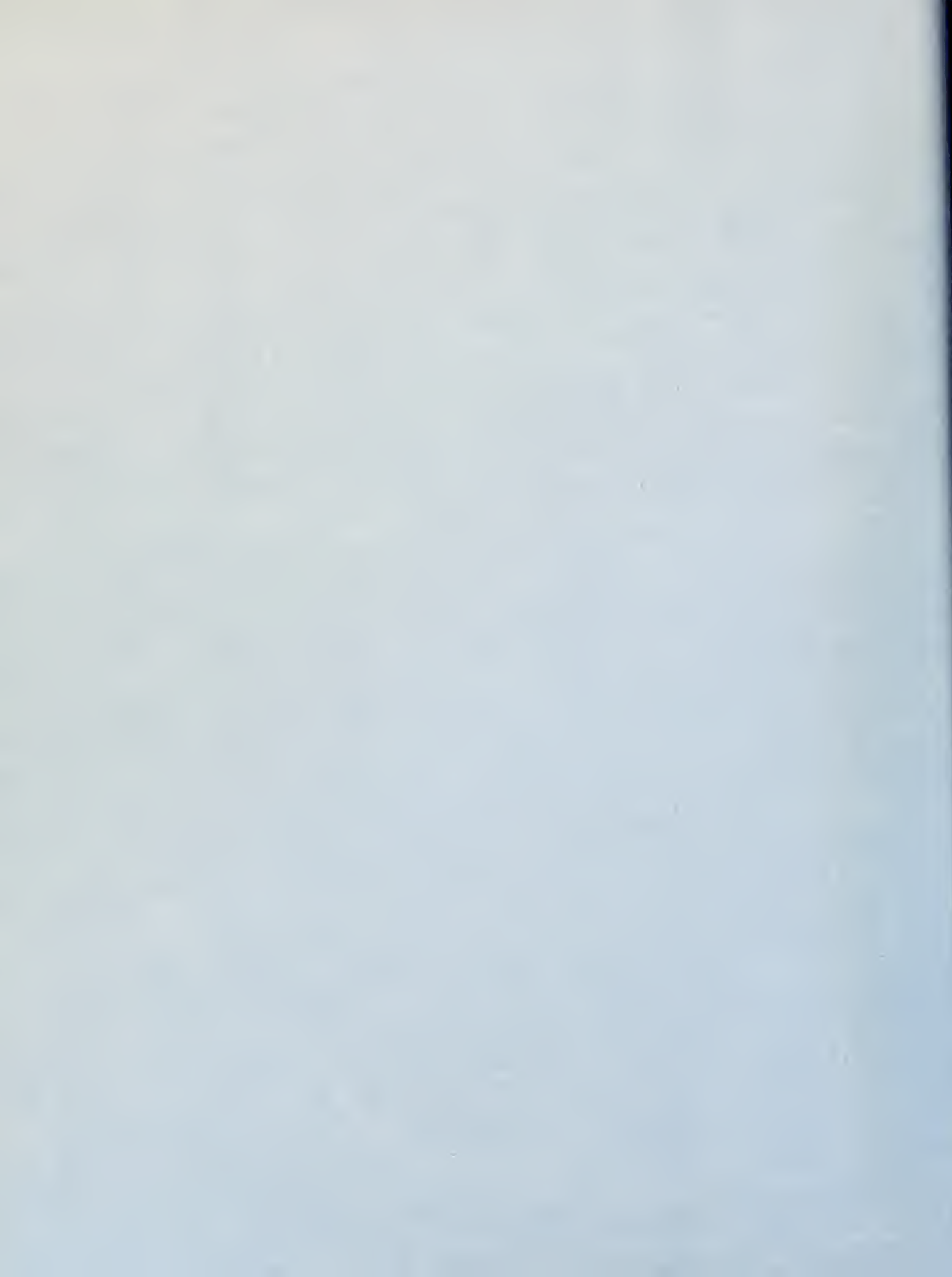


FIGURE XV

MODEL No: 2834

SERIAL No: 3

$L = 14.3'$
 $B = 3.15'$
 $H = .95' \quad L/H = 15.1$
 $\Delta = 1663 \#$
 $S = 55.0 \text{ ft}^2$
 $L/B = 4.54$
 $B/H = 3.00$
 $C_p = .659$
 $V/\sqrt{gH} = 9.10$
 $C_x = .871$
 $C_v = .573$
 $C_{PV} = .747$
 $C_w = .768$
 $C_{sw} = 2.82$

MODEL DATA

TEMP: 70°F

$V/\sqrt{gH}$	R_T
1.00	1.66
1.30	1.70
1.50	1.74
1.70	1.88
2.00	2.40
2.30	3.44
2.50	4.11
2.70	4.88
3.00	6.33
3.20	7.55
3.40	9.24
3.60	11.55
3.80	14.88
4.00	18.76
4.20	23.26

APPENDAGES: RUDDER, BULGE KEEL
TYPE: SURVEY SHIP (C46S)

③ VS ② FOR 400' SAIP

$\Delta C_D = -.0004$
 TEMP = 59°F

(K)

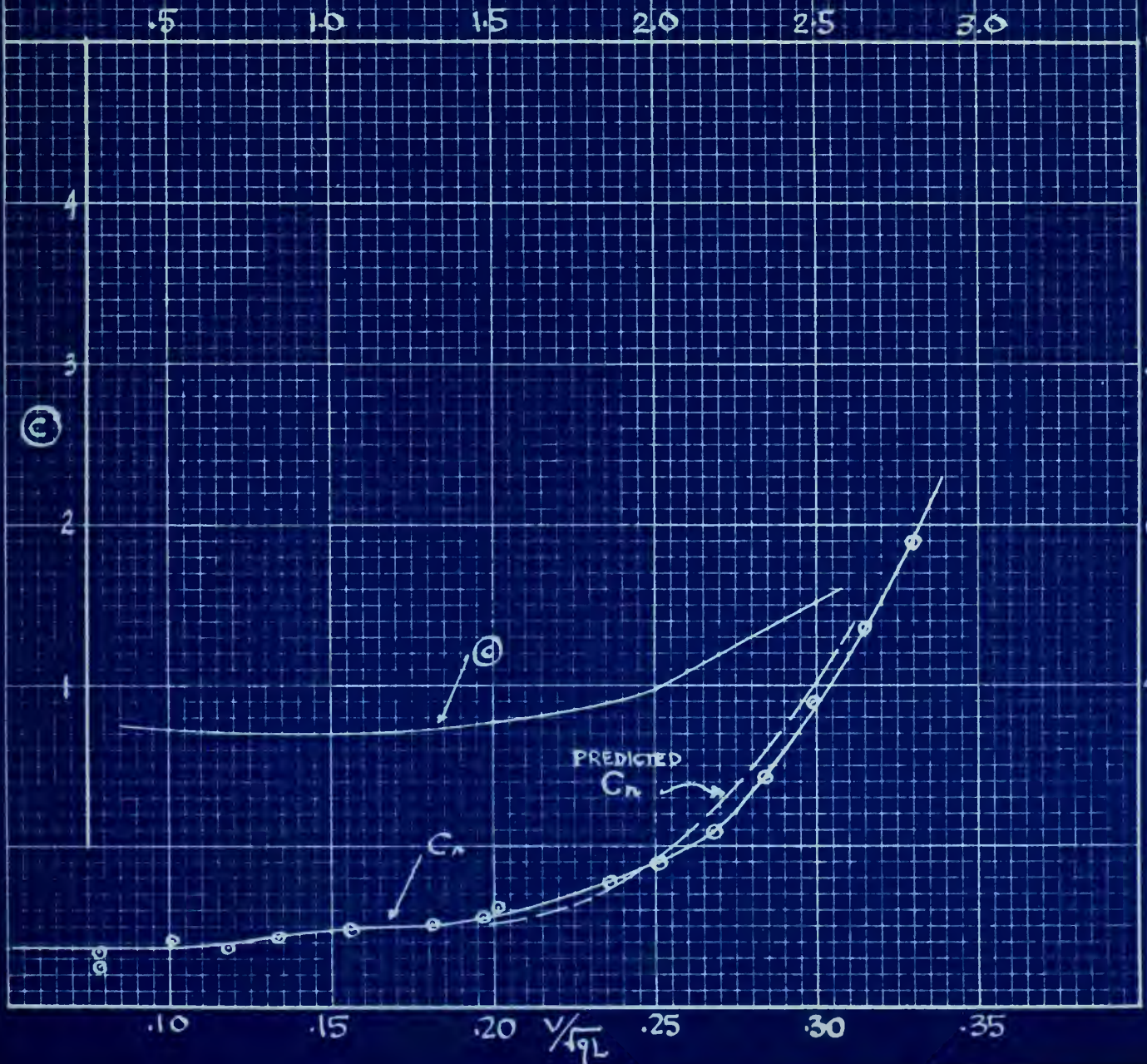


FIGURE XVI

MODEL No: 3064
(4-1-0)

$L = 8.75'$
 $B = 2.50'$
 $H = 1.0'$
 $\Delta = 802\#$
 $S = 28.78'$
 $L/B = 3.50$
 $B/H = 2.5$

$C_p = .593$
 $\frac{V}{\sqrt{gL}} = 19.20$
 $C_x = .99$
 $C_B = .588$
 $C_{PV} =$
 $C_w =$
 $C_{sw} = 2.72$

SERIAL No 4

MODEL DATA

TEMP = 68°F

V_r	R_r
1.0	.45
1.5	.94
1.75	1.20
2.0	1.78
2.25	2.40
2.50	3.25
2.75	4.50
3.0	6.94

APPENDAGES: NONE

TYPE: SERIES 53 PHB (S.B.)

③ vs ② FOR 400' SHIP

$\Delta C_s = .0004$

TEMP = 69°F

(K)

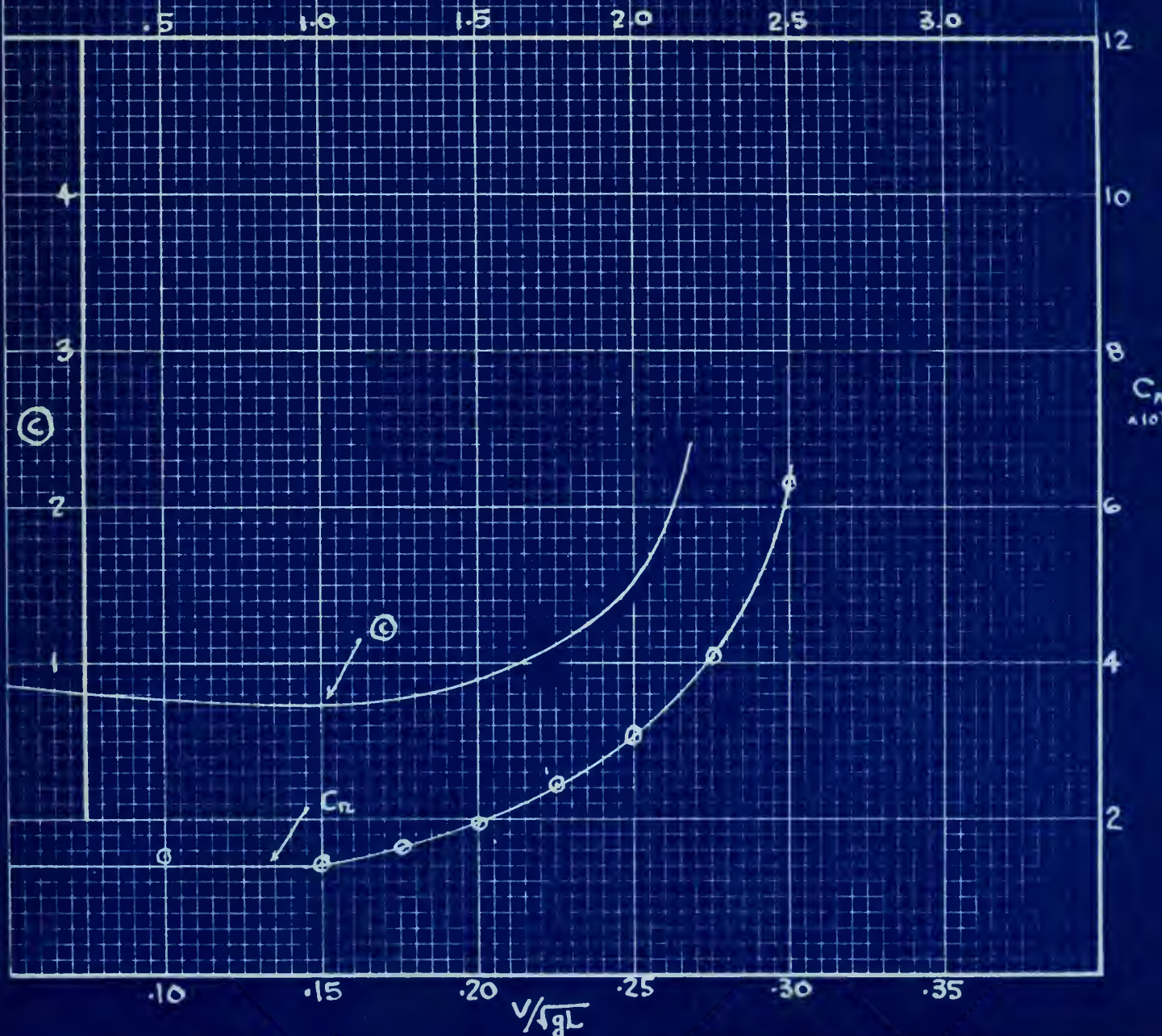


FIGURE XVII

MODEL No: 3064

(4-1-5)

SERIAL No 5

MODEL DATA

TEMP = 67°

L = 9.25'

 $C_p = .616$

B = 2.50'

 $\sqrt{C_{IL}} = 17.9$

H = 1.00'

 $C_{N1} = .99$ $\Delta = 880\#$ $C_B = .611$

S = 3095 ft

 $C_{TV} =$ $L/B = 3.70$ $C_W =$ $B/H = 2.50$ $C_{SW} = 2.72$

V_{∞}	R_T
1.0	.47
1.5	1.01
1.75	1.43
2.00	1.93
2.25	2.67
2.50	3.43
2.75	5.50
3.00	7.74
3.10	9.25

APPENDAGES: NONE

TYPE: SERIES 53 PMB (S.B.)

④ vs ③ FOR 400' SHIP

 $\Delta C_S = .0004$

TEMP = 59°F

(4)

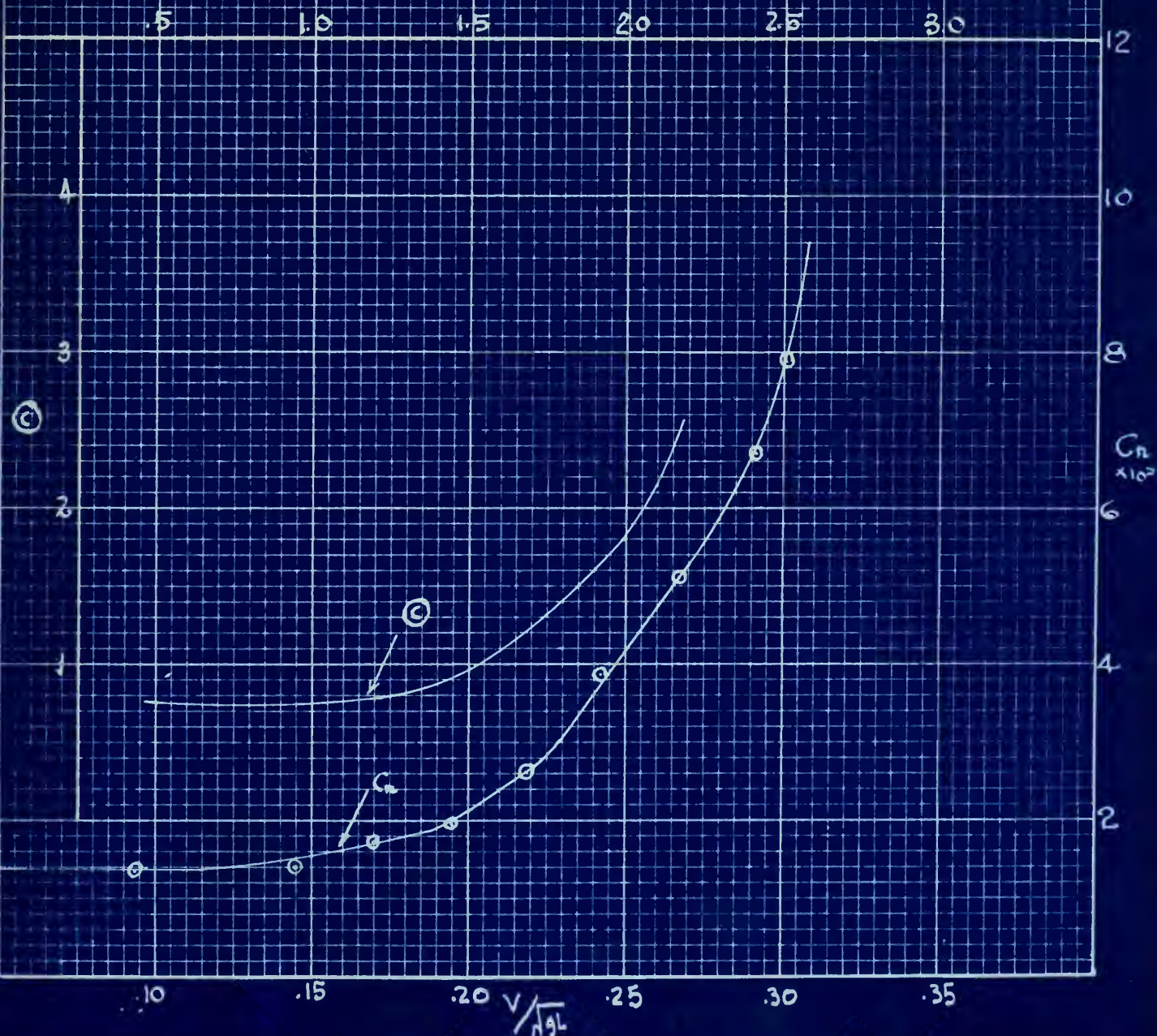


FIGURE XVIII

MODEL No: 306A
(4-1-1)

SERIAL No: 6

MODEL DATA

TEMP = 66°F

L = 9.75'
B = 2.50'
H = 1.00'
Δ = 957#
S = 33.11 ft.
L/B = 3.90
B/H = 2.50
C_p = .635
V_(H) = 16.65
C_x = .99
C_B = .631
C_{pv} =
C_w =
C_{sw} = 2.72

V _r	R _r
1.00	.48
1.50	1.02
1.75	1.40
2.00	1.88
2.25	2.66
2.50	4.20
2.75	6.40
3.00	9.26
3.10	10.50

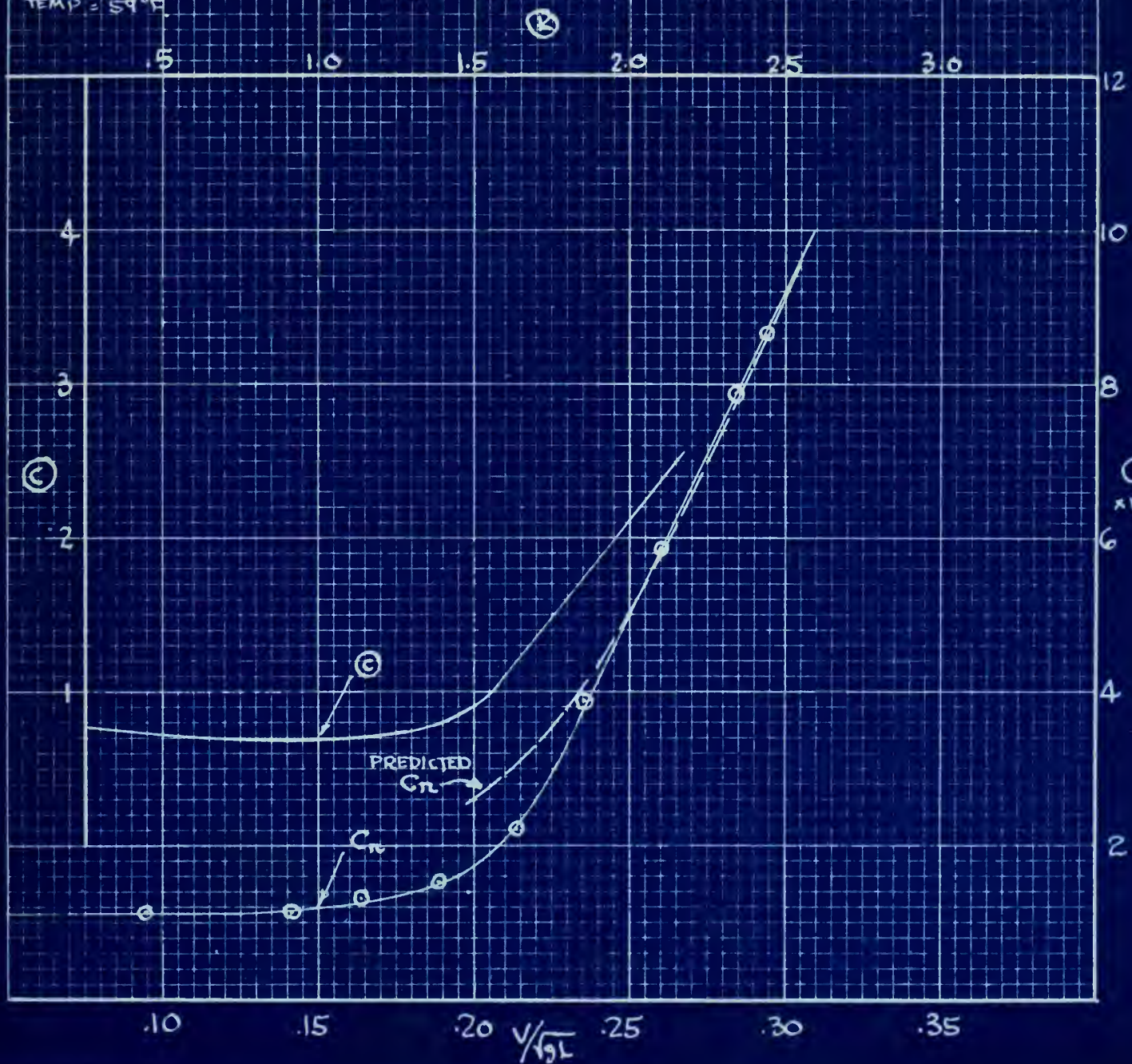
APPENDAGES: NONE

TYPE: SERIES 53 PHB (S.B.)

© vs C FOR 400' SHIP

ΔC_f = .0004

TEMP = 59°F



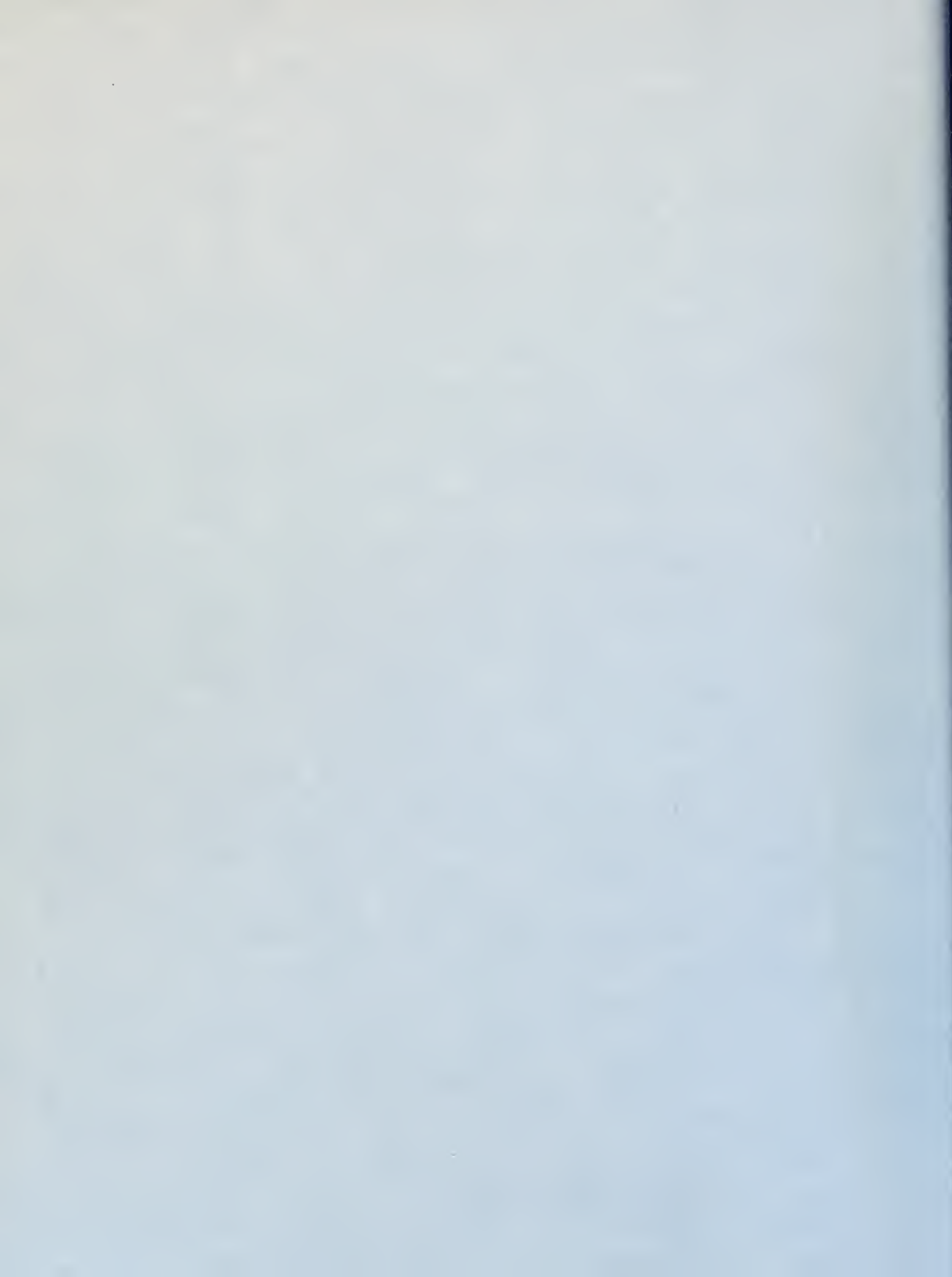


FIGURE XIX

MODEL No: 306A
(4-1-15)

$L = 10.25'$

$B = 2.50'$

$H = 1.00'$

$\Delta = 1035 \#$

$S = 35.28 \%$

$L/B = 4.10$

$B/H = 2.50$

$C_p = .653$

$\sqrt{L}/L^3 = 15.4$

$C_x = .99$

$C_b = .659$

$C_{pv} =$

$C_w =$

$C_{sw} = 2.70$

SERIAL No: 7

MODEL DATA

TEMP = 66°F

V_x	R_T
1.00	.52
1.50	1.11
1.75	1.47
1.90	1.94
2.00	2.67
2.25	4.18
2.50	6.40
3.00	10.15
3.10	11.70
3.20	13.68

APPENDAGES: NONE

TYPE: SERIES 53 PAB (S.B.)

© vs © FOR 400 SHIP

$\Delta C_1 = .0004$

TEMP = 59°F

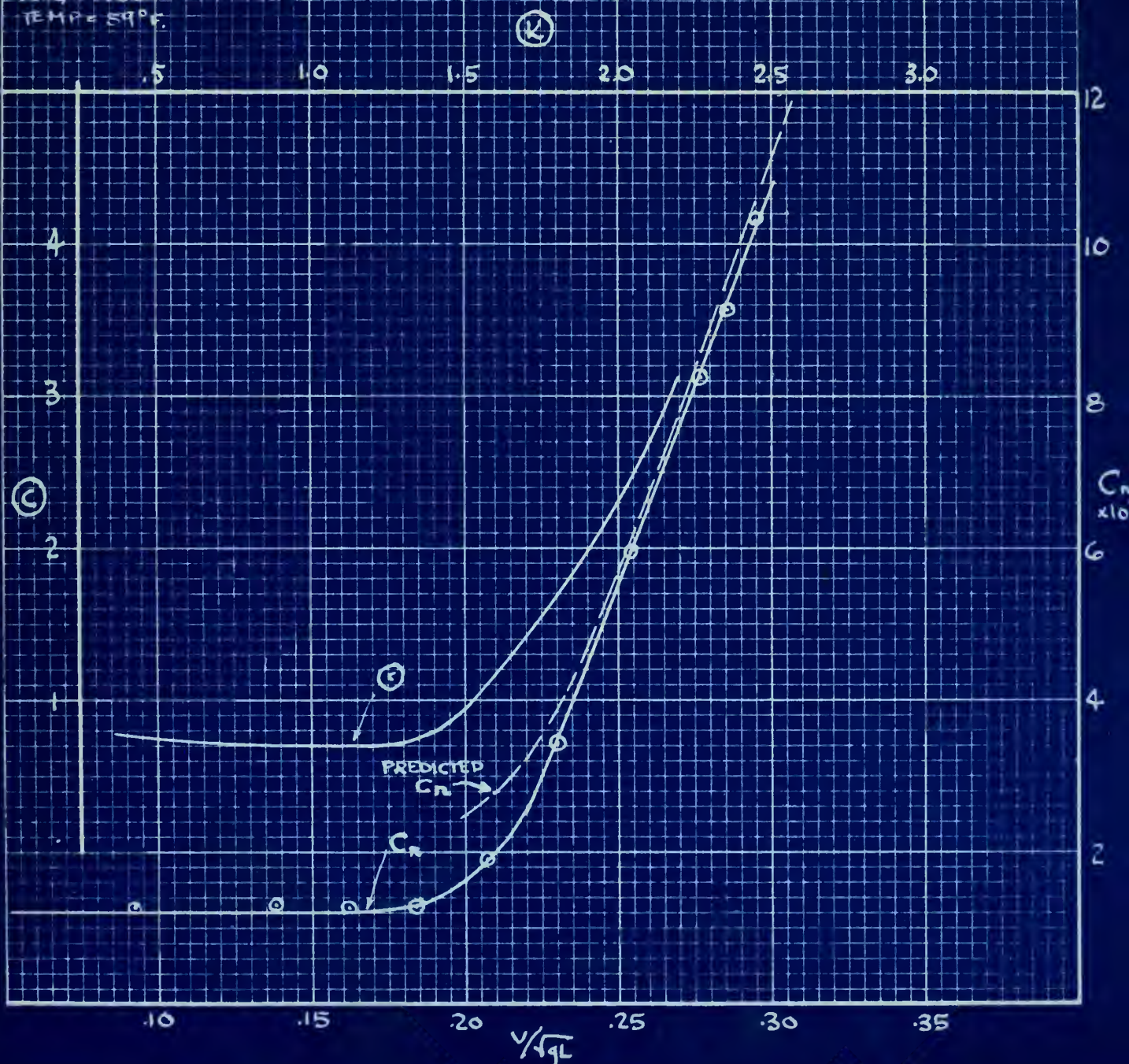


FIGURE XX

MODEL No: 3064
(4-1-2.0)

$L = 10.75'$
 $B = 2.50'$
 $H = 1.00'$
 $\Delta = 1112 \#$
 $S = 37.44 \#$
 $T/B = 4.30$
 $B/H = 2.50$

$C_F = .669$

$V_{X,110} = 14.37$

$C_K = .99$

$C_b = .564$

$C_{PV} =$

$C_W =$

$C_{SW} = 271$

SERIAL No: 8

MODEL DATA

TEMP = 65°F

V_h	R_T
1.00	.57
1.50	1.20
1.75	1.60
2.00	2.10
2.25	2.70
2.50	3.38
2.75	4.71
3.00	6.97
3.10	12.98

APPENDAGES: NONE
 TYPE: SERIES 53 PMP (S.B.)

③ vs ② FOR 400' SHIP

$AC_s = .0004$

TEMP = 59°F

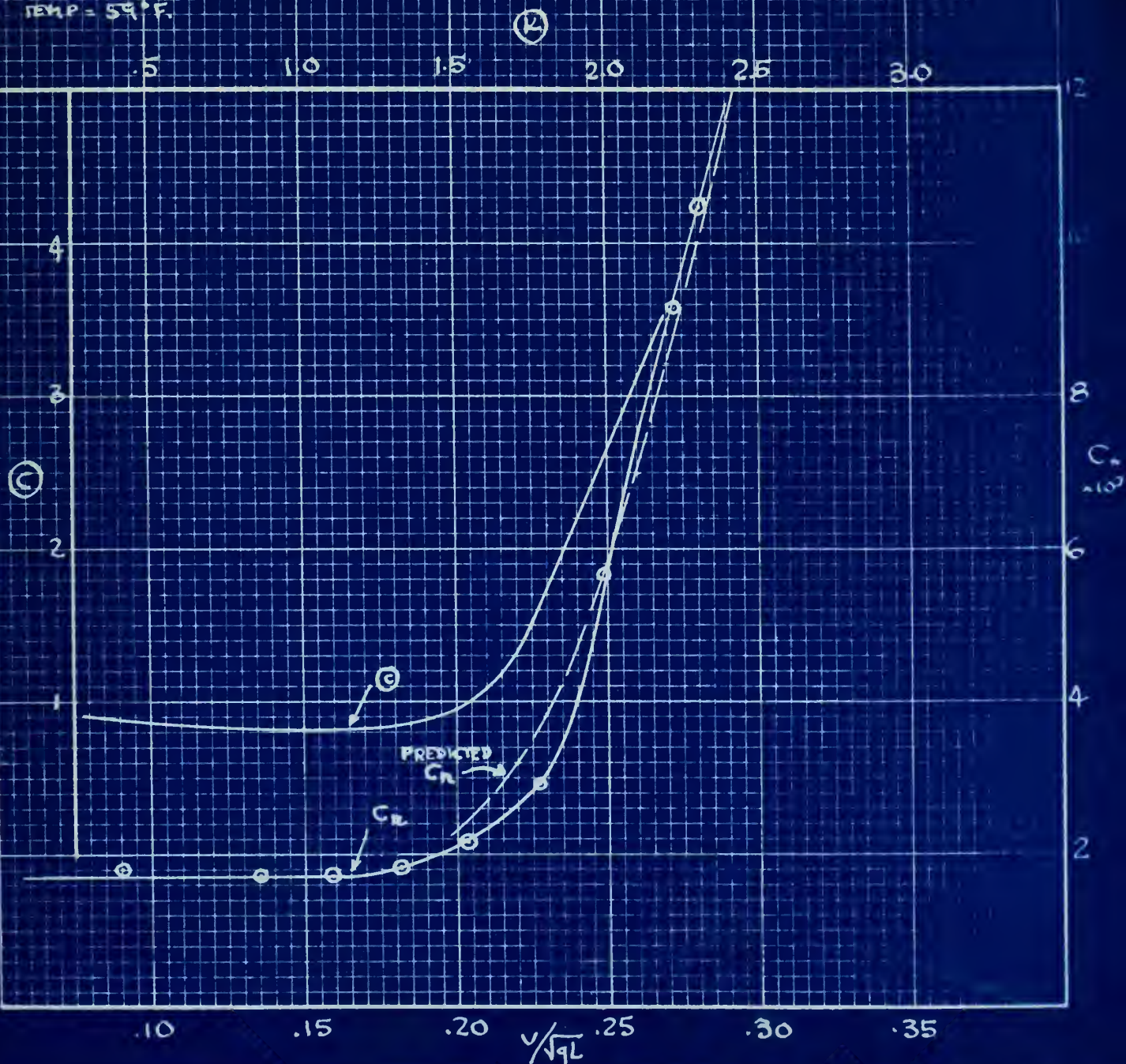


FIGURE XXI

MODEL No: 3044

(4-1-2.5)

 $L = 11.25'$ $C_p = .685$ $B = 2.50'$ $\frac{S}{L} = 13.38$ $H = 1.00'$ $C_x = .99$ $\Delta = 1190$ $C_B = .678$ $S = 39.61$ $C_{PV} =$ $L/B = 4.50$ $C_W =$ $B/H = 2.50$ $C_{SW} = 2.71$

SERIAL No: 9

MODEL DATA

TEMP = 64.5

V_x	R_r
1.00	.13
1.50	1.41
1.75	1.80
2.00	2.28
2.25	2.90
2.50	3.52
2.75	5.15
3.00	9.95
3.10	11.93
3.20	16.10

APPENDAGES: NONE

TYPE: SERIES S3 PHB (S.B.).

① vs ② FOR 400' SHIP

 $\Delta C_F = .0004$

TEMP: 59°F

②

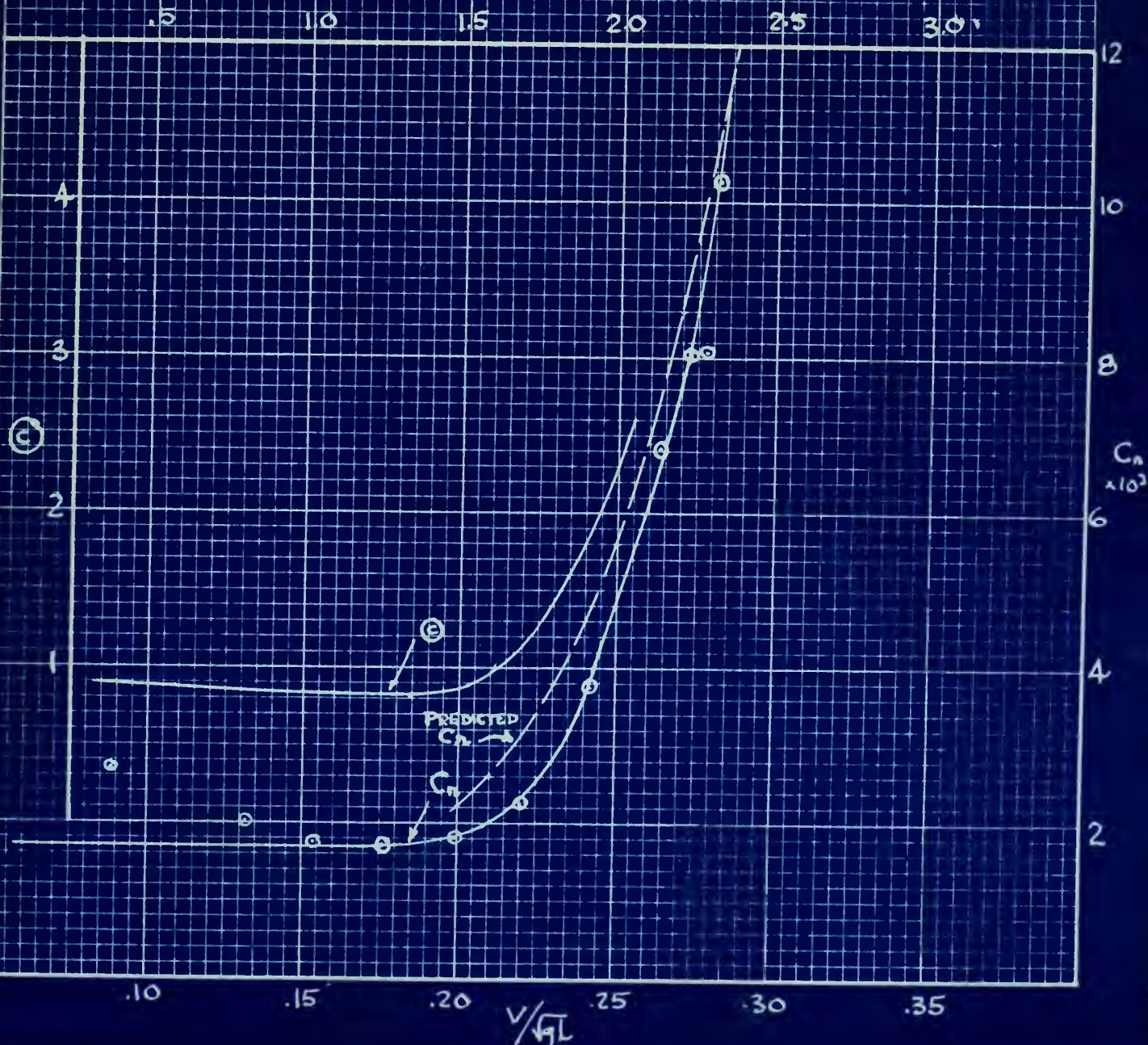


FIGURE XXII

MODEL NO: 3064

(4-1-4.0)

SERIAL NO: 10

MODEL DATA

TEMP = 63°

L = 12.75'

Cp = .722

B = 2.50'

 $\frac{V}{(L)} = 11.08$

H = 1.00'

Cx = .99

 $\Delta = 1422^*$

Cb = .716

S = 46.10 ft

Cpw =

 $\frac{1}{B} = 5.10$

Cw =

B/H = 2.50

Csw = 2.71

Vx	Rr
1.000	1.69
1.500	1.42
1.750	1.90
2.000	2.55
2.250	3.68
2.500	4.76
2.750	6.05
3.000	8.74
3.250	10.75
3.500	13.05

APPENDAGES: NONE

TYPE: SERIES 53 P.M.P. (S.B.)

© vs © FOR 400' SHIP

 $\Delta C_d = .0004$

TEMP = 69°F.

(K)

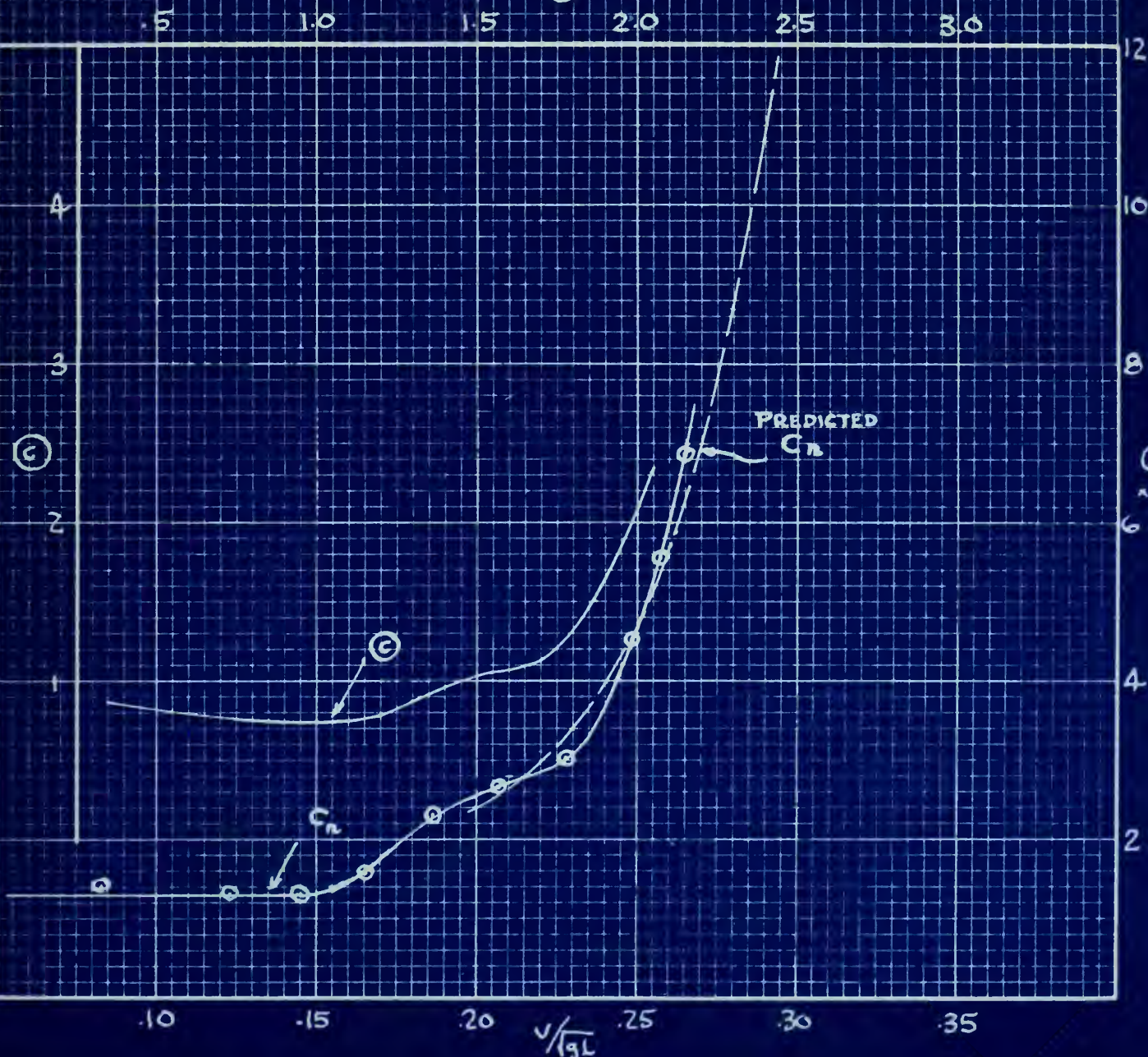




FIGURE XXIII

Model No: 3065
(5-1-0)

SERIAL No: 11

MODEL DATA

TEMP: 63°F

L = 10'
B = 2.50'
H = 1.00'
Δ = 928 #
S = 32.93 #
L/B = 4.0
B/H = 2.50
C_p = .60
V_(IL) = 14.82
C_x = .99
C_b = .595
C_M =
C_w =
C_{sw} = 2.70

V _u	R _u
1.00	.62
1.50	1.21
1.75	1.57
2.00	2.00
2.25	2.60
2.50	3.35
2.75	4.30
3.00	5.60
3.10	6.32

APPENDAGES: NONE
TYPE: SERIES 53 PHB (S.B.)

⊙ vs ⊗ FOR 400' SHIP
Δ C_p = .0004
TEMP: 59°F

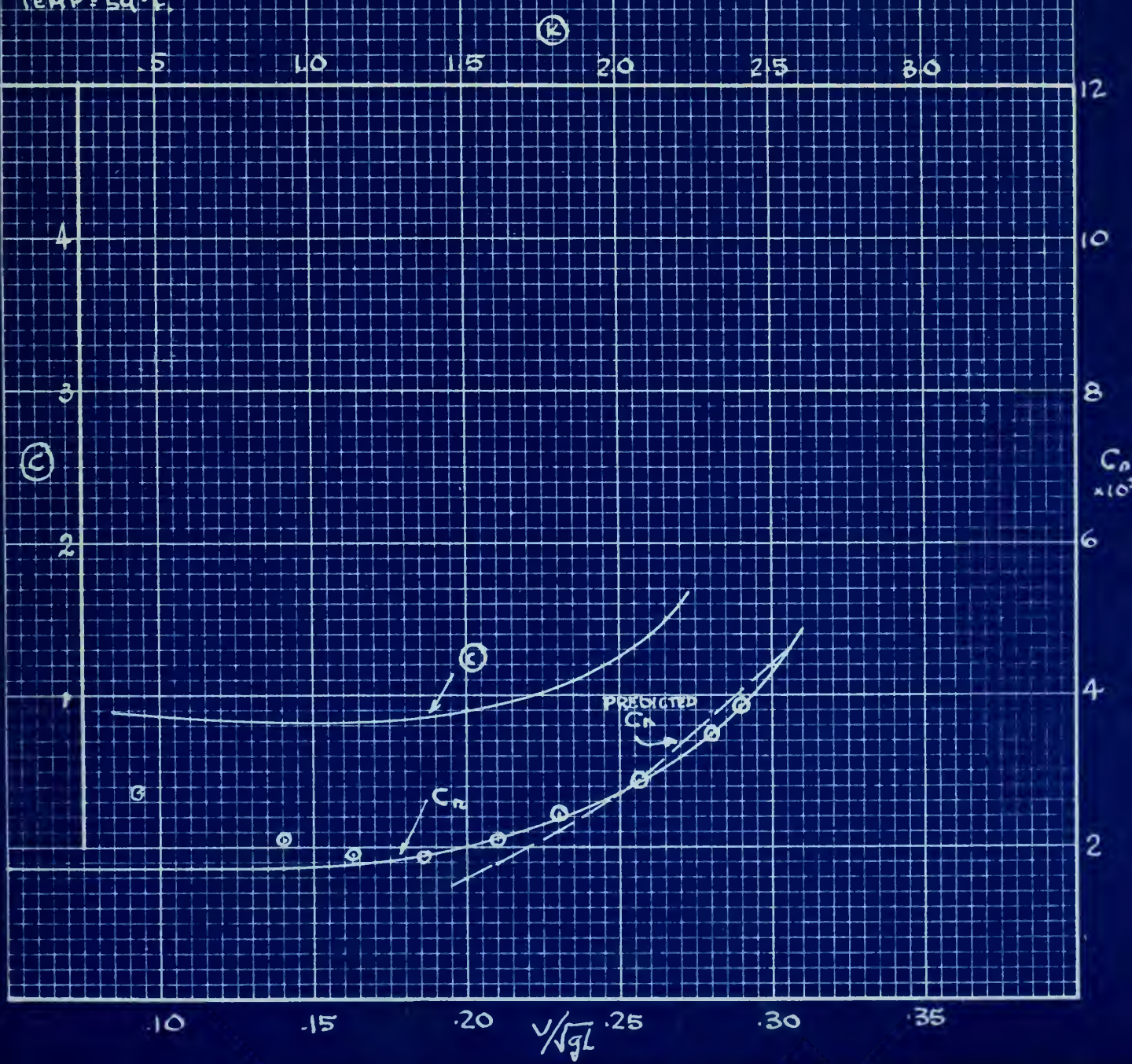


FIGURE XXIV

MODEL NO: 3065 (5-4-5)

SERIAL NO 12

$L = 10.5'$
 $B = 2.50'$
 $H = 1.00'$
 $\Delta = 1005 \#$
 $S = 35.09 \text{ d}$
 $L/B = 4.2$
 $B/H = 2.50$

$C_p = .620$
 $\gamma/L^3 = 13.90$
 $C_{KZ} = .99$
 $C_b = .614$
 $C_{ru} =$
 $C_w =$
 $C_{sw} = 2.70$

MODEL DATA

TEMP = 43°F

V_k	R_z
1.00	.47
1.50	1.01
1.75	1.40
2.00	1.93
2.25	2.61
2.50	3.51
2.75	4.74
3.00	6.38
3.10	7.27
3.20	8.32
3.30	10.10

APPENDAGES: NONE

TYPE: SERIES 53 PHB (S.B)

© VS © FOR 400' SHIP

 $\Delta C_L = 10004$

TEMP = 59°F

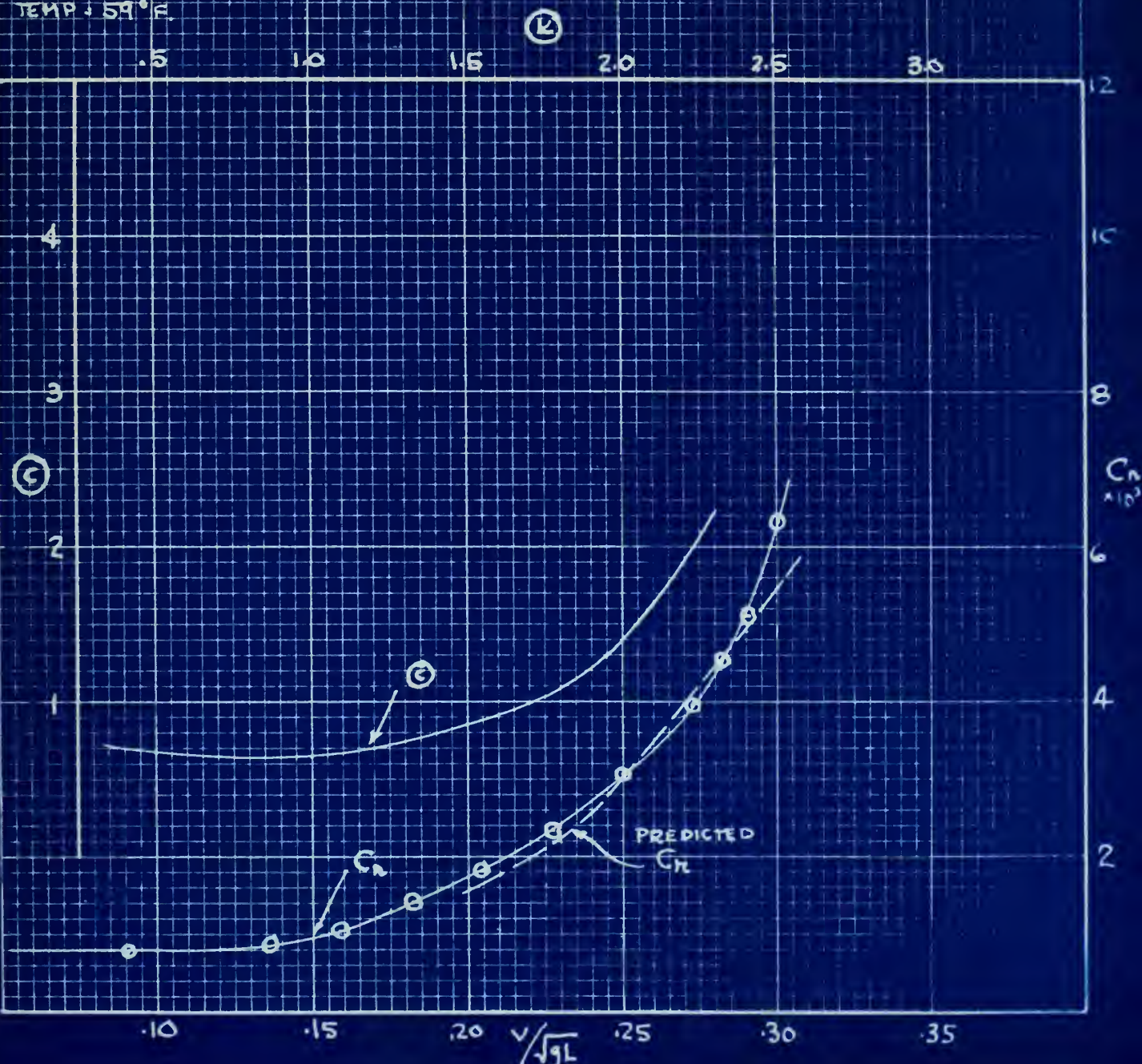




FIGURE XXV

MODEL No: 3065 (5-1-1)

SERIAL NO: 13

 $L = 11.0'$ $C_p = .638$

MODEL DATA

TEMP = 60°F

 $B = 2.50'$ $\frac{V}{(10)^3} = 13.10$ $H = 1.00'$ $C_x = .99$ $\Delta = 1083 \text{ lb}$ $C_b = .632$ $S = 37.25 \text{ ft}^2$ $C_{pv} =$ $L/B = 4.40$ $C_w =$ $B/H = 2.50$ $C_{sw} = 2.70$

APPENDAGES: NONE

TYPE: SERIES S3 PMB (S.B.)

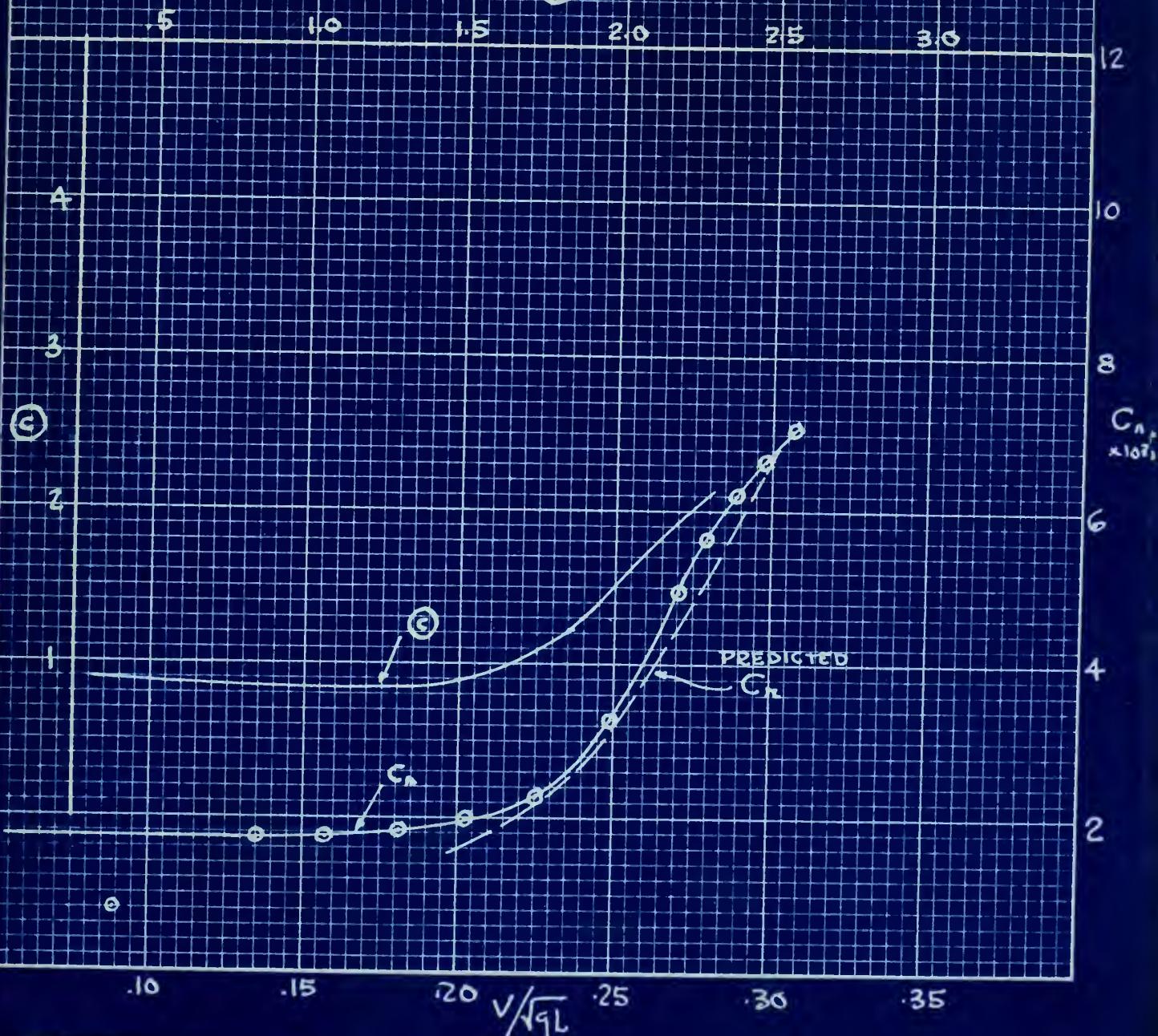
V_L	R_T
1.00	.63
1.50	1.27
1.75	1.71
2.00	2.22
2.25	2.87
2.50	3.48
2.75	5.10
3.00	7.63
3.10	9.86
3.25	10.80
3.30	11.10
3.40	12.25

© vs © FOR 400' SHIP

 $\Delta C_g = .0004$

TEMP = 50°F

(K)



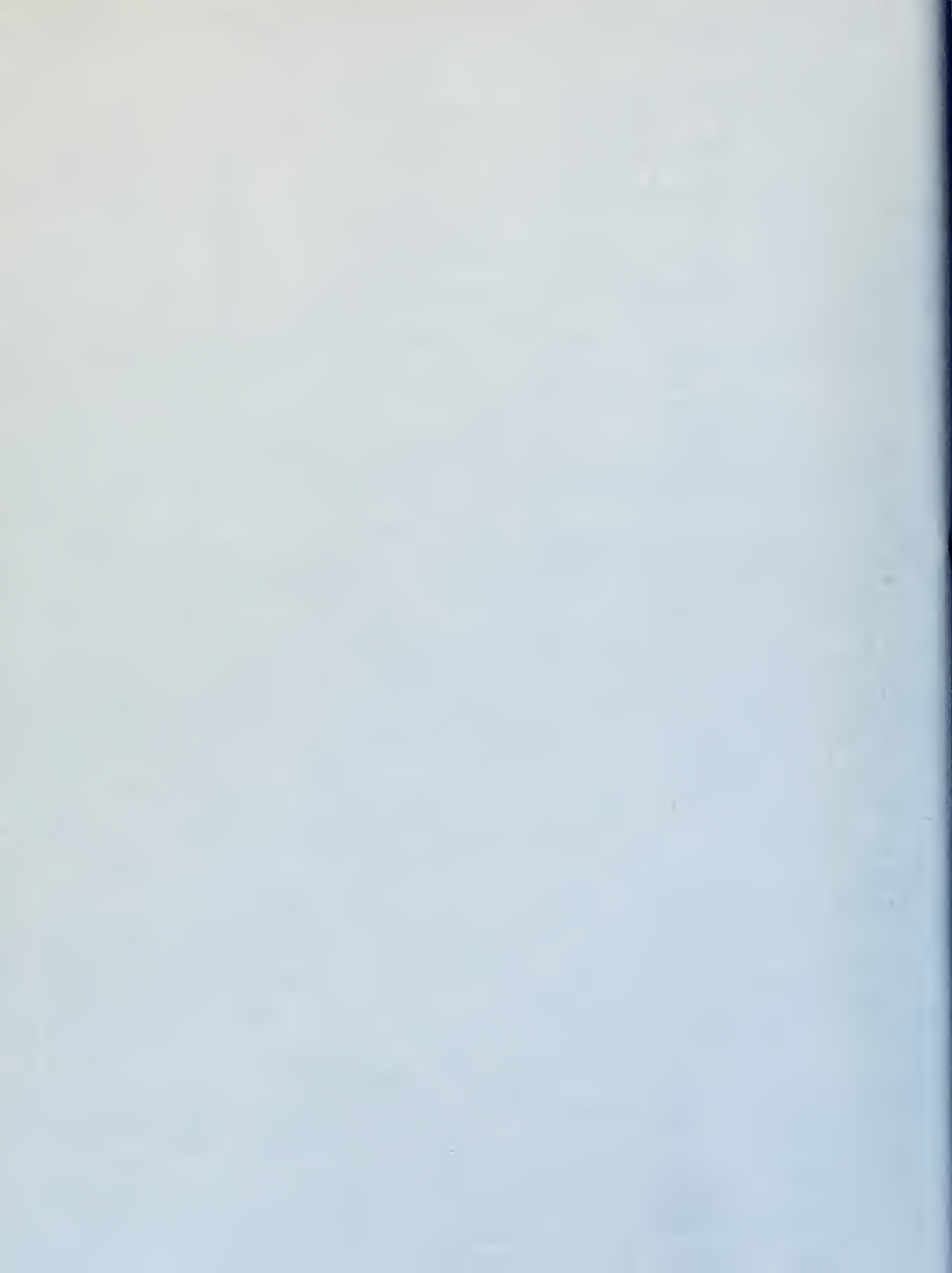


FIGURE XXVI

MODEL NO: 3065 (5-1-1.5)

SERIAL NO: 14

 $L = 11.5'$ $C_p = .653$ $B = 2.50'$ $V/U^2 = 12.25$ $H = 1.00'$ $C_k = .99$ $\Delta = 1160 \#$ $C_b = .647$ $S = 39.42 \text{ ft}$ $C_{pv} =$ $L/B = 4.60$ $C_w =$ $B/W = 2.50$ $C_{sw} = 2.70$

MODEL DATA

TEMP = 60°F

V/U	R_T
1.00	1.43
1.50	1.81
1.75	1.74
2.00	2.39
2.25	2.92
2.50	3.72
2.75	5.10
3.00	7.89
3.10	9.86
3.20	10.95
3.30	12.70

APPENDAGES: NONE

TYPE: SERIES 53 PMB (S.B.)

① vs ② FOR 400' SHIP

 $\Delta C_D = .0004$

TEMP = 59°F

②

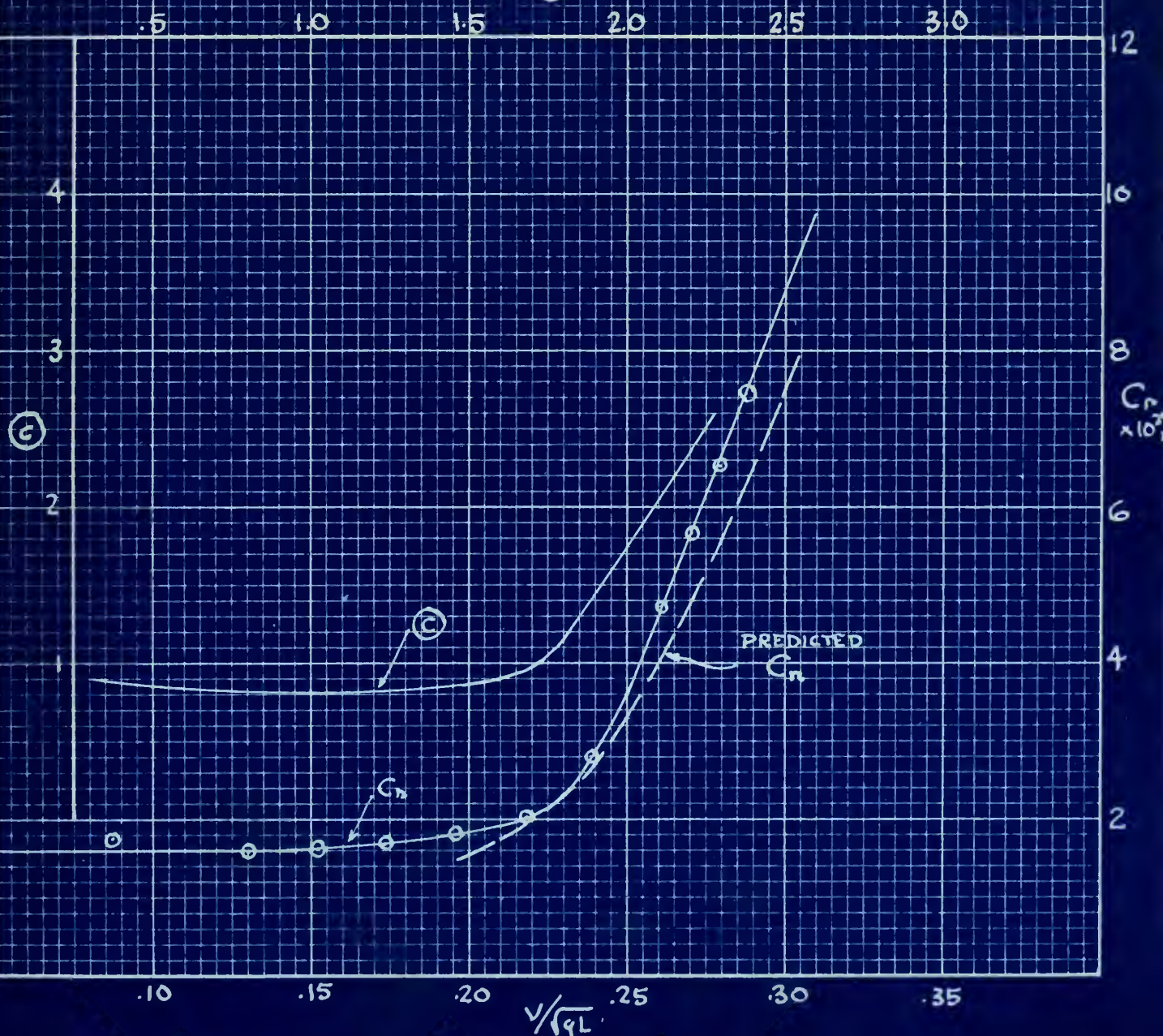


FIGURE XXVII

MODEL No: 3065 (S-1-2)

SERIAL No: 15

 $L = 12.0'$ $C_p = .668$ $B = 2.50'$ $V/(L)^{3/2} = 11.44$ $H = 1.00'$ $C_{af} = .99$ $\Delta = 1238 \#$ $C_b = .661$ $S = 41.58 \text{ ft}$ $C_{pv} =$ $L/B = 4.8$ $C_{wl} =$ $B/H = 2.50$ $C_{sw} = 2.73$

MODEL DATA

TEMP = 61°F

V_u	R_u
1.00	.70
1.50	1.47
1.75	1.90
2.00	2.37
2.25	2.85
2.50	3.24
2.75	4.90
3.00	7.80
3.10	9.55
3.20	11.95
3.30	13.45

APPENDAGES: NONE

TYPE: SERIES 53 PH8 (S.B)

C vs R FOR 400' SHIP

 $\Delta C_s = 1.0004$

TEMP = 50°F

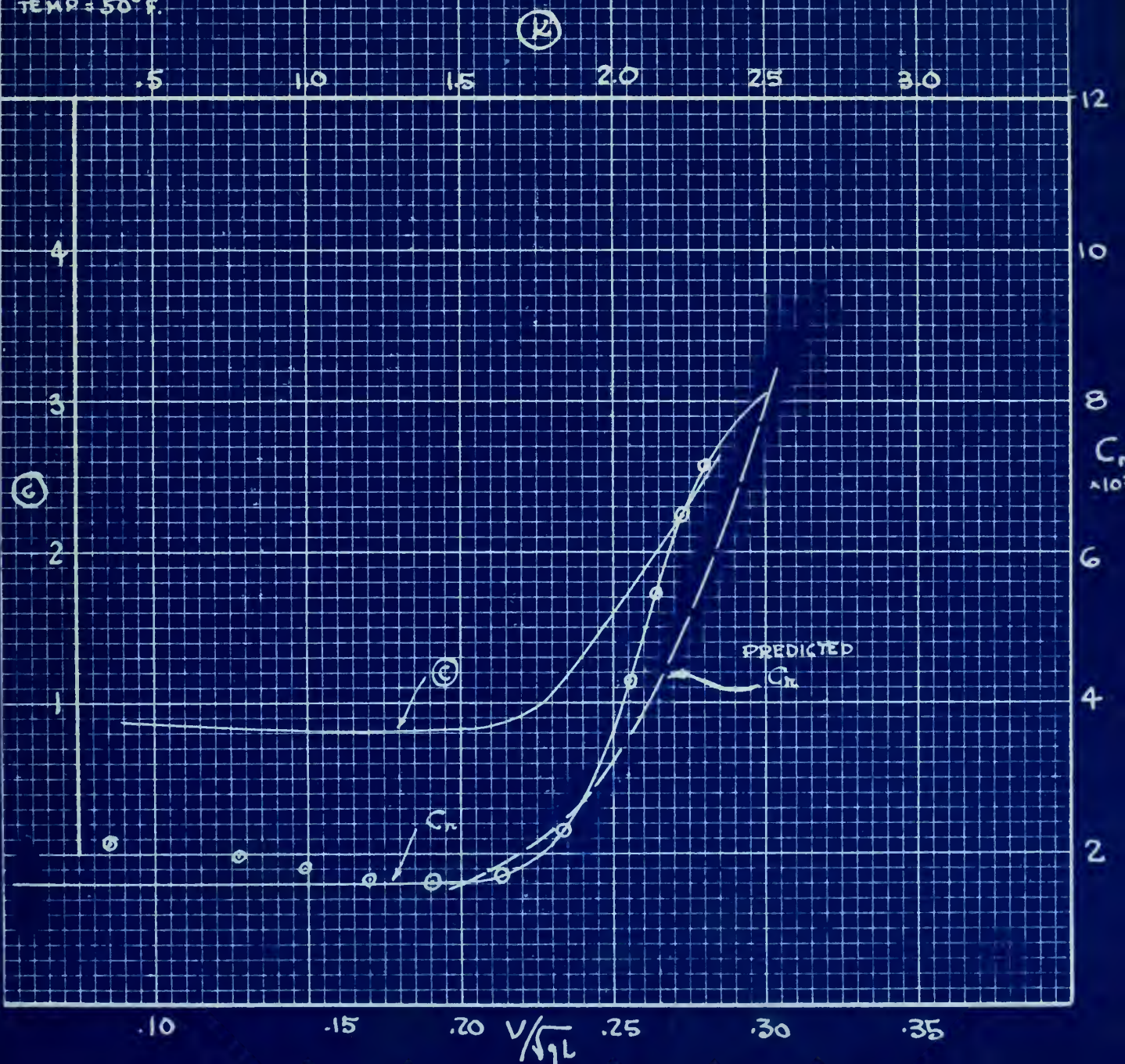


FIGURE XXVIII

MODEL NO: 3065 (5-1-35)

SERIAL NO: 16

L: 13.50'

 $C_p = .705$

MODEL DATA

B: 2.50'

 $\nabla/L^3 = 9.57$

TEMP: 59°F

H: 1.00'

 $C_x = .99$ V_L R_T $\Delta = 1470 \#$ $C_b = .700$

1.00 .76

S: 48.08 ft

 $C_{pv} =$

1.50 1.60

 $L/B = 5.40$ $C_{wv} =$

1.75 2.10

 $B/H = 2.50$ $C_{sw} = 2.70$

2.00 2.72

2.25 3.45

2.50 4.28

2.75 5.25

3.00 6.50

3.25 7.87

3.50 9.95

3.75 12.25

APPENDAGES: NONE

TYPE: SERIES 53 PMB (S.B.)

© US N FOR 400 SHIP

 $\Delta C_p = .0004$

TEMP: 59°F

(K)

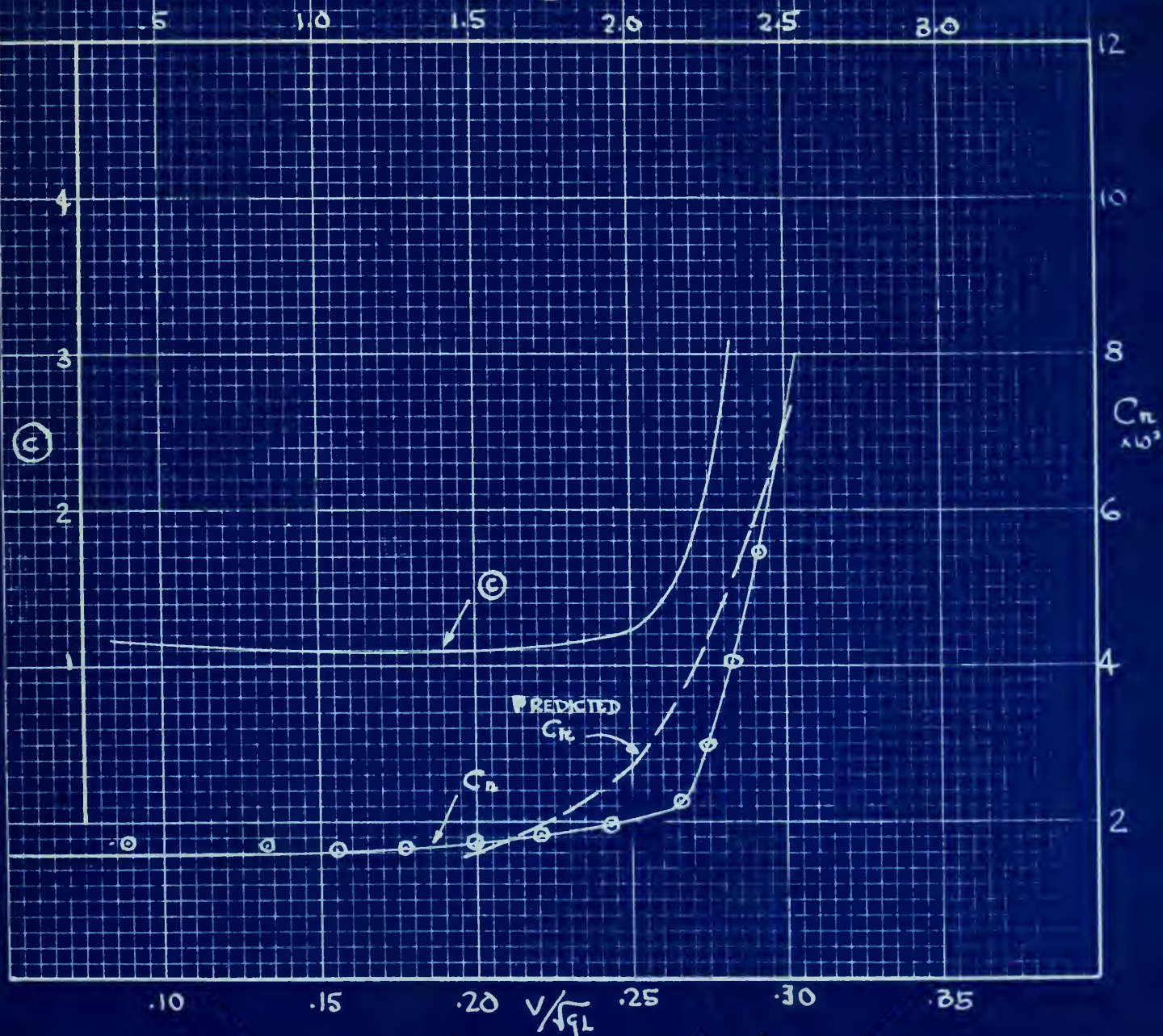




FIGURE XXIX

MODEL No: 3068 (2-2-1)

SERIAL No: 17

L= 12.25'

$C_p = .588$

B= 2.50'

$\sqrt{W}^2 = 9.69$

H= 1.00'

$C_x = .99$

A= 1112*

$C_b = .584$

S= 40.04 d

$C_{pv} =$

L/B= 4.90

$C_{we} =$

B/H= 2.50

$C_{fw} = 2.72$

MODEL DATA

TEMP = 59°F

V_n	R_T
1.00	.61
1.50	1.25
1.75	1.63
2.00	2.12
2.25	2.60
2.50	3.12
2.75	3.67
3.00	4.28
3.10	5.50
3.20	6.16
3.30	7.03
3.40	8.10
3.50	9.40
3.60	10.98

APPENDAGES: NONE

TYPE: SERIES S3 PHB (G.B)

⑤ vs ③ FOR 400' SHIP

$\Delta C_S = .0004$

TEMP = 59°F

②

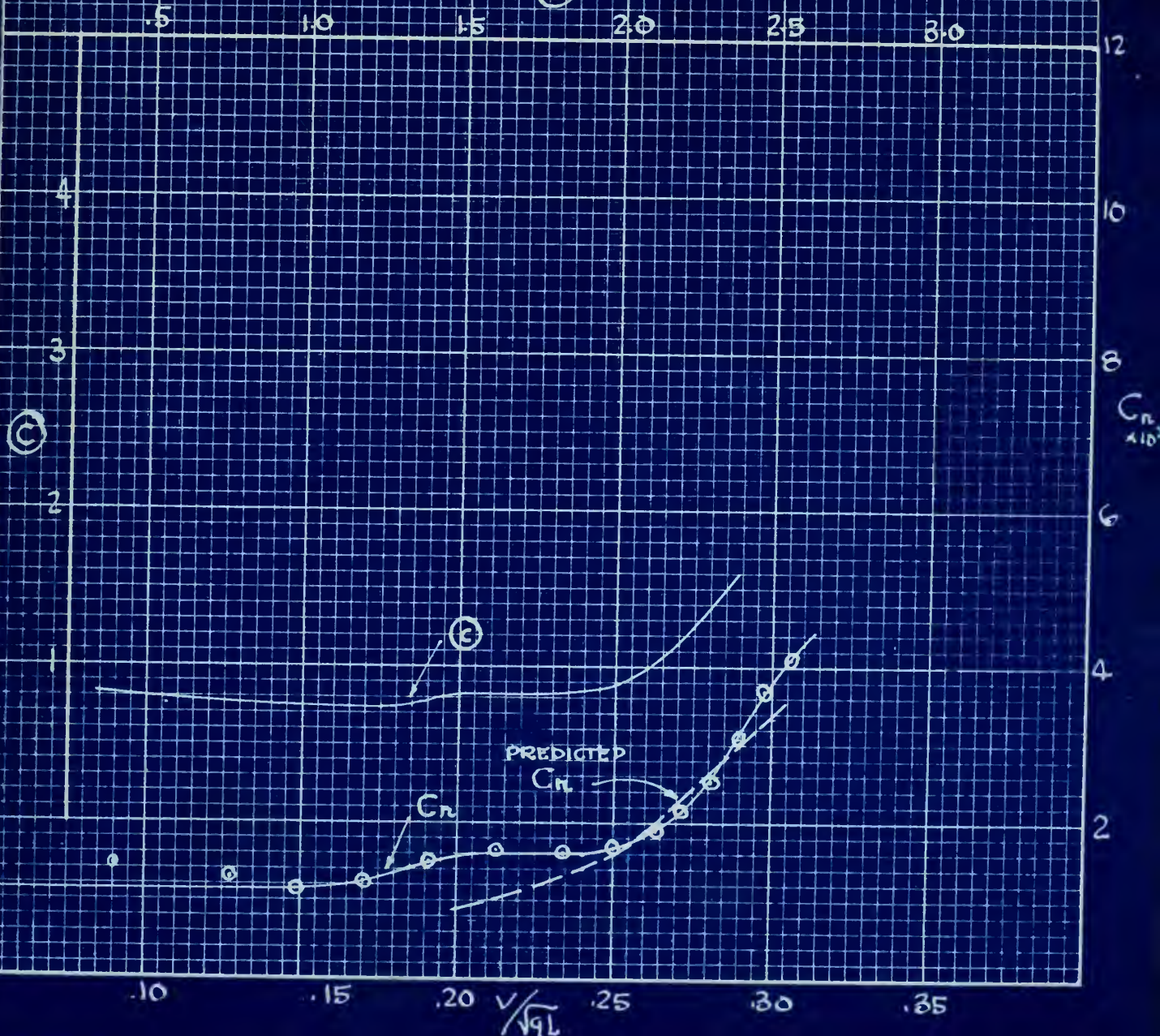


FIGURE XXX

MODEL No: 3070 (4-2-15)

SERIAL No: 18

 $L = 11.50'$ $C_p = .642$

MODEL DATA

 $B = 2.50'$ $V/\sqrt{g} = 12.06$

TEMP: 54°F.

 $H = 1.00'$ $C_{xt} = .99$ V_L R_T $\Delta = 114.1 \text{ ft}$ $C_b = .637$

1.00

1.60

 $S = 39.19 \text{ ft}$ $C_{vt} =$

1.50

1.41

 $L/B = 4.60$ $C_{wt} =$

1.75

1.82

 $B/H = 2.50$ $C_{sw} = 2.71$

2.00

2.38

2.25

2.98

2.50

4.13

2.75

2.60

3.00

10.77

3.10

11.85

3.20

13.75

APPENDAGES: NONE

TYPE: SERIES E3 PH3 (S.B)

Ⓒ vs Ⓐ FOR 400' SHIP

 $\Delta C_R = .0004$

TEMP = 54°F.

Ⓐ

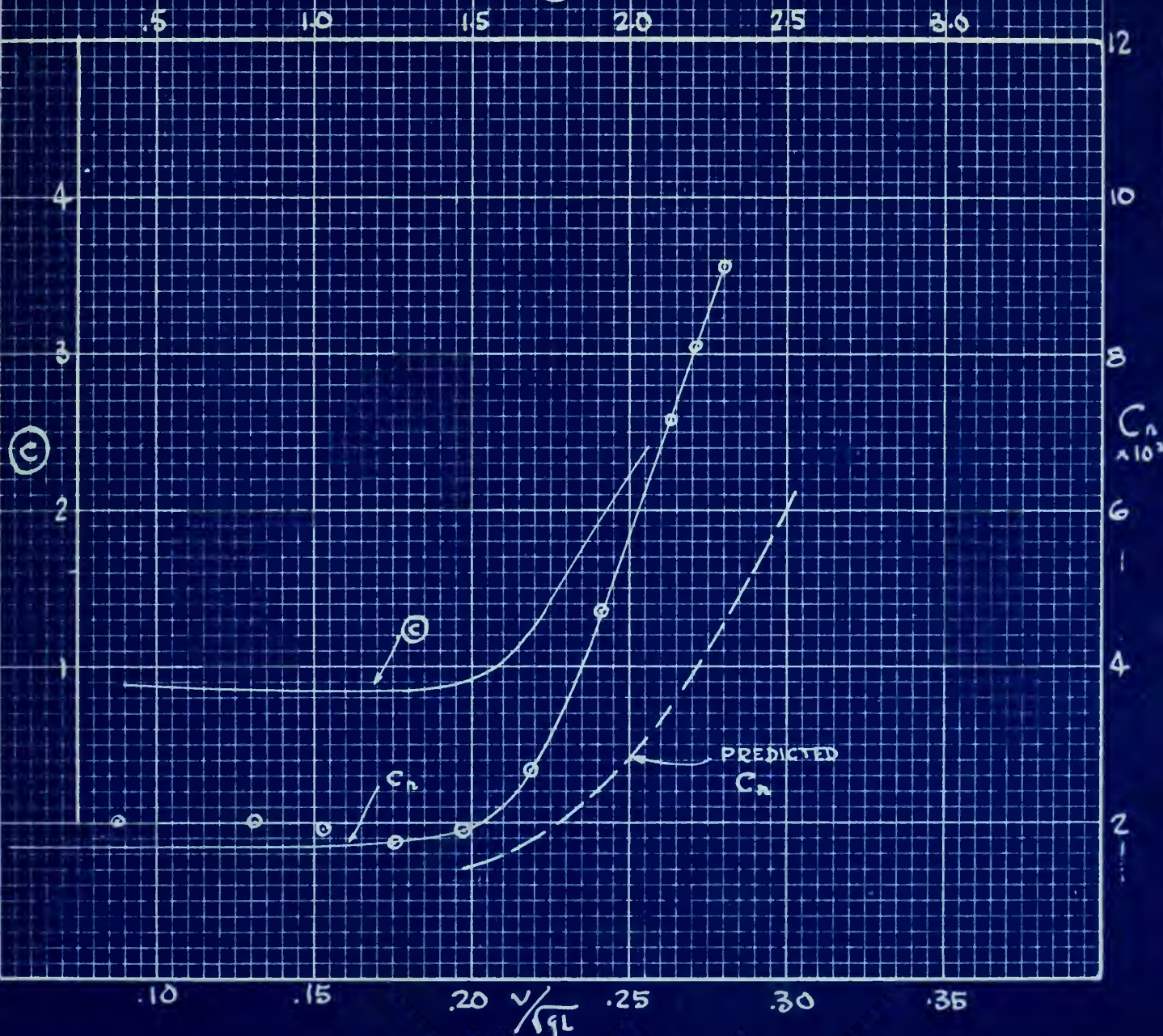


FIGURE XXXI

MODEL No: 3102

SERIAL No: 19

L = 15.0'

 $C_p = .629$

B = 3.583'

 $\nabla_{(H)}^2 = 10.25$

H = 1.200' (2 THM BIS)

 $C_k = .848$ $\Delta = 2145\#$ $C_b = .534$

S = 57.711

 $C_{pv} =$

L/B = 4.18

 $C_{WV} =$

B/H = 2.99

 $C_{SW} = 2.54$

MODEL DATA

TEMP: T₁₀F

V _K	R _T
1.04	.711
1.50	1.49
2.00	2.63
2.50	4.24
3.00	6.64
3.20	7.86
3.40	9.34
3.50	10.35
3.60	11.72
3.80	16.03
4.00	20.25
4.20	24.50
4.40	28.25
4.60	32.10

APPENDAGES: NONE

TYPE: COAST GUARD CUTTER (C.G.)

C vs D FOR 400' SHIP

 $\Delta C_D = .0004$

TEMP = 59°F

(K)

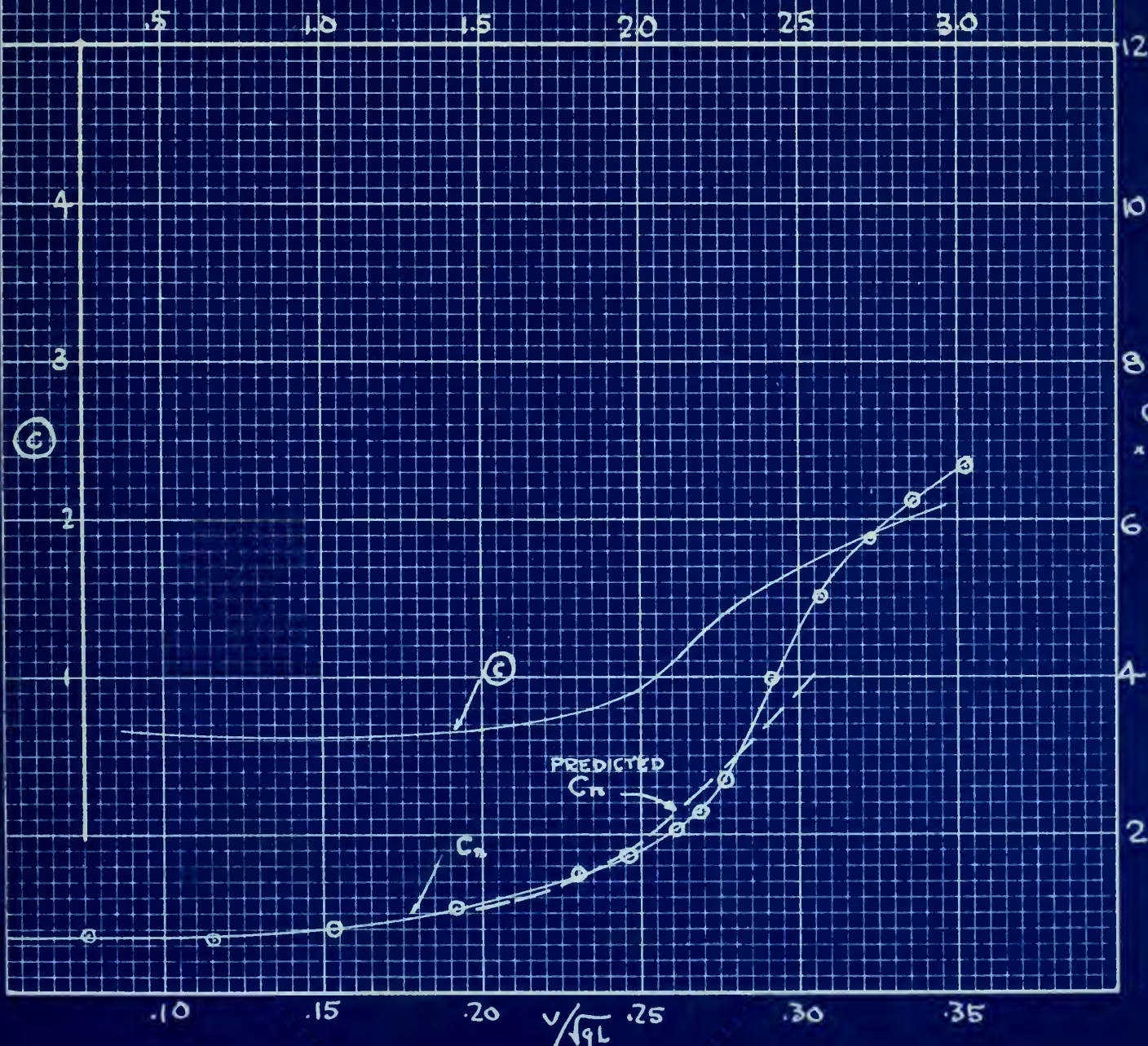




FIGURE XXXII

MODEL No: 3121A

SERIAL No: 20

 $\lambda = 16.416'$ $C_p = .712$

MODEL DATA

 $B = 3.07'$ $\sqrt{V/(H)} = 11.08$

TEMP = 80°F

 $H = 1.47' \text{ EK}$ $C_x = .926$ V_k R_T $\Delta = 3048 \#$ $C_b = .66$

1.00 .99

 $S = 73.884 \text{ d}$ $C_{pv} =$

1.50 1.94

 $L/R = 5.34$ $C_w =$

2.00 3.30

 $B/H = 2.09$ $C_{sw} = 2.61$

2.50 4.46

APPENDAGES: RUDDER

2.60 5.85

TYPE: FREIGHT - PASSENGER

2.80 7.09

(1)

2.80 8.54

3.10 9.82

3.20 10.16

3.30 11.10

3.40 12.15

3.50 13.50

C vs K FOR 400' SHIP

3

 $AC_s = .0004$

TEMP = 59°F

(2)

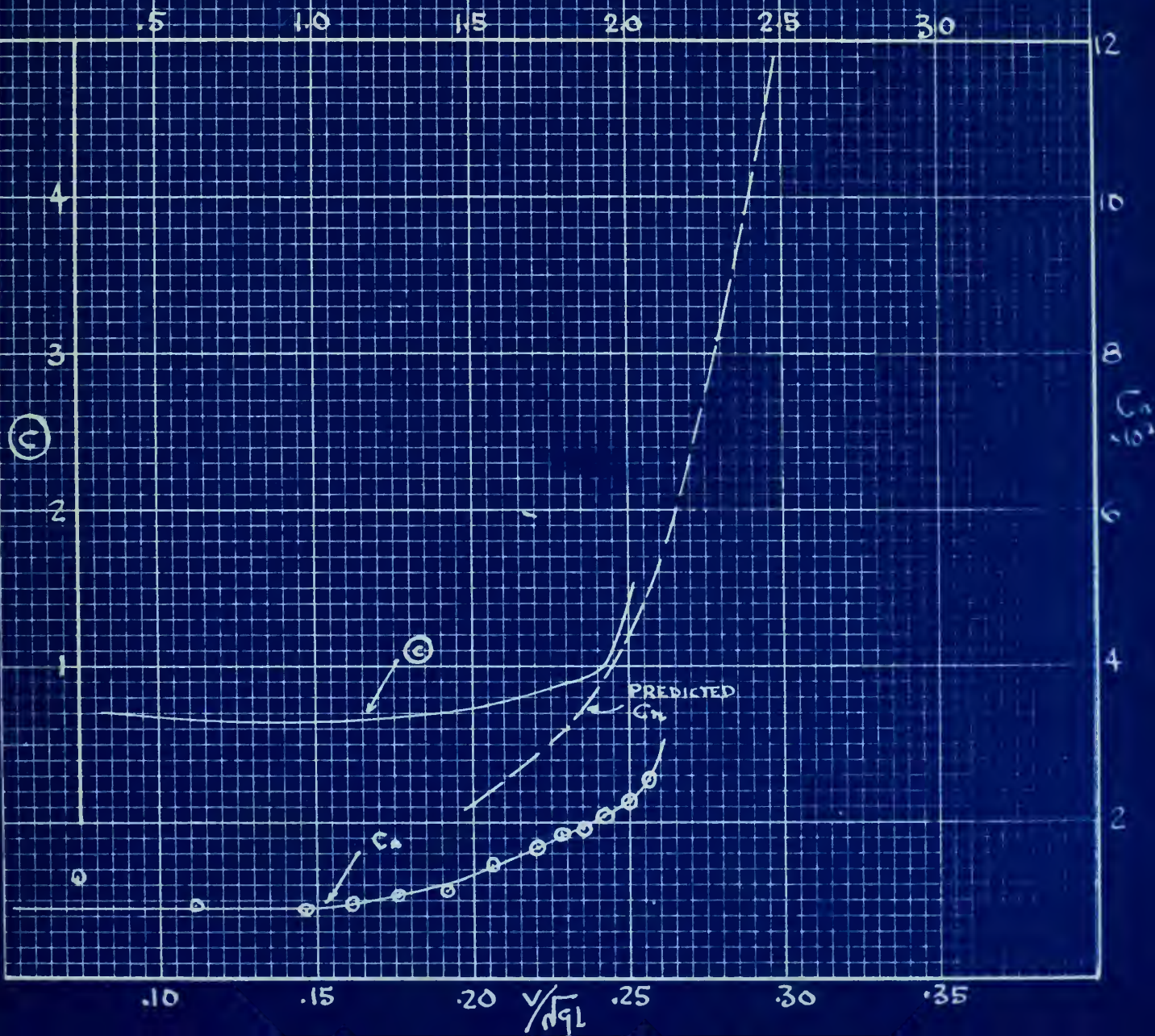


FIGURE XXXIII

MODEL No: 3121 B

SERIAL No: 21

L: 16.0'

 C_p : .702

MODEL DATA

B: 3.07'

 $\sqrt{V/|L|}$: 9.01

TEMP: 80°F

H: 1.175' EK

 C_x : .91 V_n R_n Δ : 1298 # C_b : .639

1.00 .91

S: 63.963 d

 C_{DVS}

1.50 1.49

 L/B : 5.22 C_W

2.00 2.88

 B/H : 2.61 C_{SW} : 2.64

2.10 3.44

2.40 4.14

2.60 5.00

2.80 5.98

3.00 7.10

3.10 7.74

3.20 8.40

3.30 9.20

3.40 10.17

3.50 11.41

3.60 13.20

APPENDAGES: RUDDER

TYPE: FREIGHT-PASSENGER (L)

③ vs ② FOR 400' SHIP

 ΔC_f : .0004

TEMP: 59°F

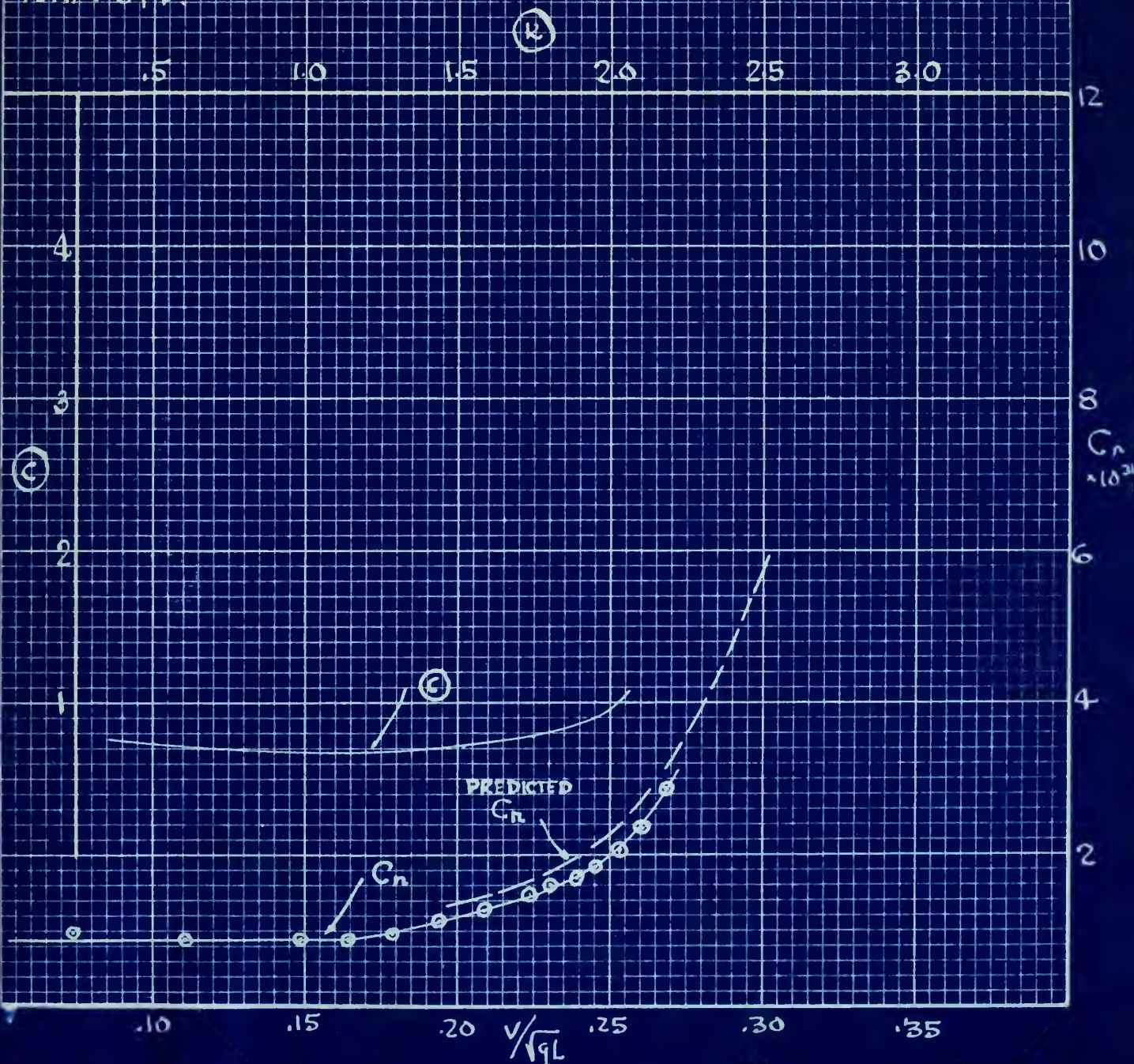


FIGURE XXXIV

MODEL No: 3132

SERIAL No: 22

MODEL DATA

TEMP: 68°F.

$L = 20.637'$

$B = 3.45'$

$H = 1.552'$

$\Delta = 5416 \text{ lb}$

$S = 112.292 \text{ ft}$

$L/B = 5.99$

$B/H = 2.22$

$C = .807$

$V/(H)^3 = 9.82$

$C_k = .972$

$C_b = .784$

$C_{pe} = .88$

$C_w = .92$

$C_{sh} = 2.66$

 V_k W_k

1.00 1.56

1.20 2.48

1.50 3.20

2.00 4.10

2.50 5.12

2.70 5.72

2.80 6.35

2.90 7.00

3.00 7.68

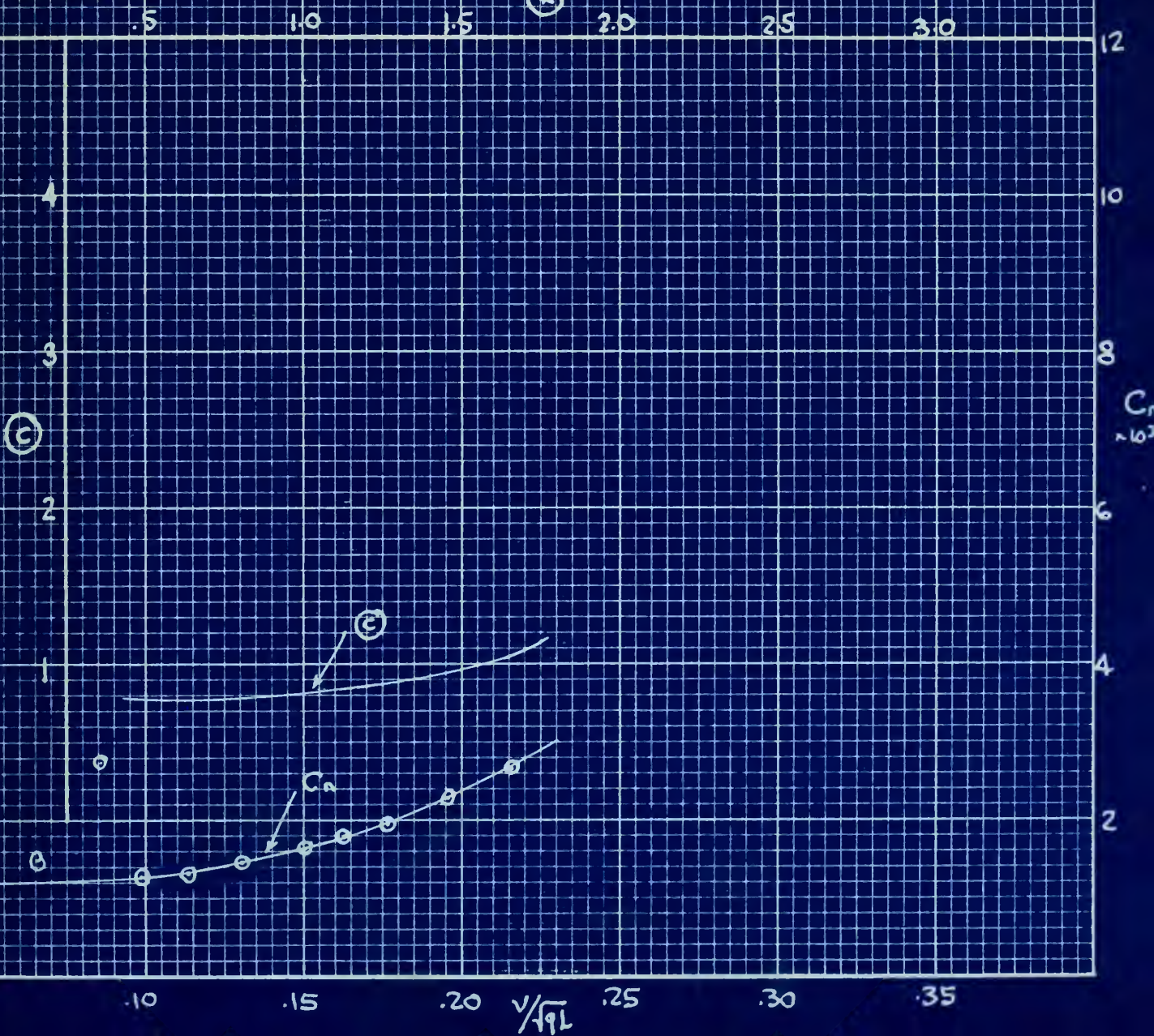
APPENDAGES: SHAFT, STEMS, RUDDER.

TYPE: DREDGE (U.S.A.E.)

C vs K FOR 400' SHIP

 $\Delta C_L = .0004$

TEMP. = 59°F



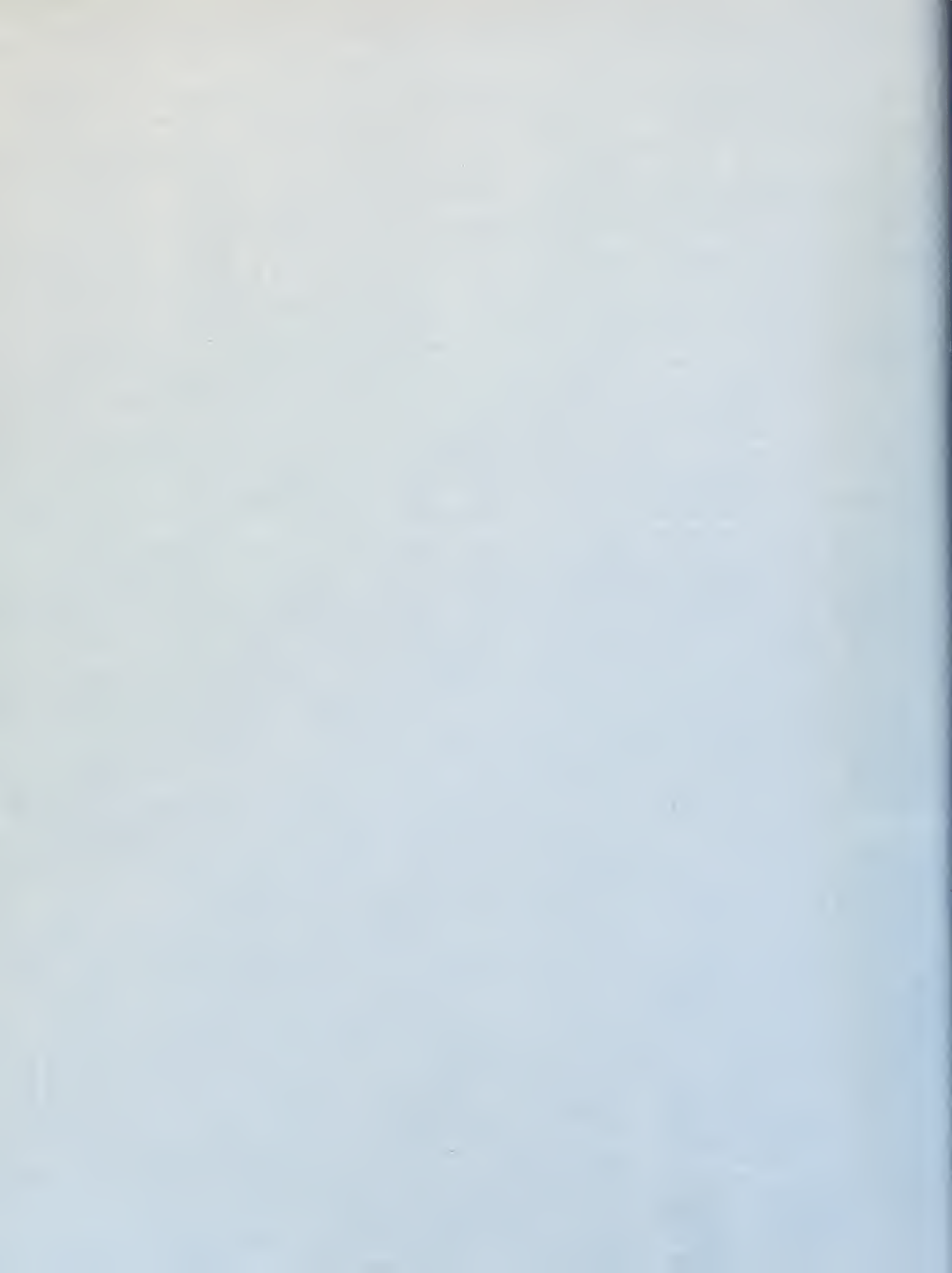


FIGURE XXXV

MODEL NO: 3138 A

SERIAL NO: 23

$L = 14.7'$
 $B = 3.428'$
 $H = 1.553'$
 $\Delta = 2631 \text{ *}$
 $S = 65.867 \text{ ft}$
 $L/B = 4.29$
 $B/H = 2.21$
 $C_p = .620$
 $V/\sqrt{gH} = 13.30$
 $C_{x1} = .068$
 $C_{x2} = .540$
 $C_{p1} = .107$
 $C_{m1} = .772$
 $C_{m2} = 2.05$

MODEL DATA

TEMP: 68°F

$V/\sqrt{gH}$	R_T
1.00	.82
1.50	1.80
2.00	3.21
2.50	5.17
2.75	6.42
3.00	8.02
3.10	8.80
3.20	9.52
3.30	10.19
3.40	10.83
3.50	11.85
3.60	13.50
3.80	17.50
4.00	22.10
4.20	27.15

APPENDAGES: - NONE

TYPE: HARBOR TUG. VT 119 (M)

(C) vs (K) FOR 400' SHIP

$\Delta C_3 = 000.4$
 TEMP: 54°F

(K)

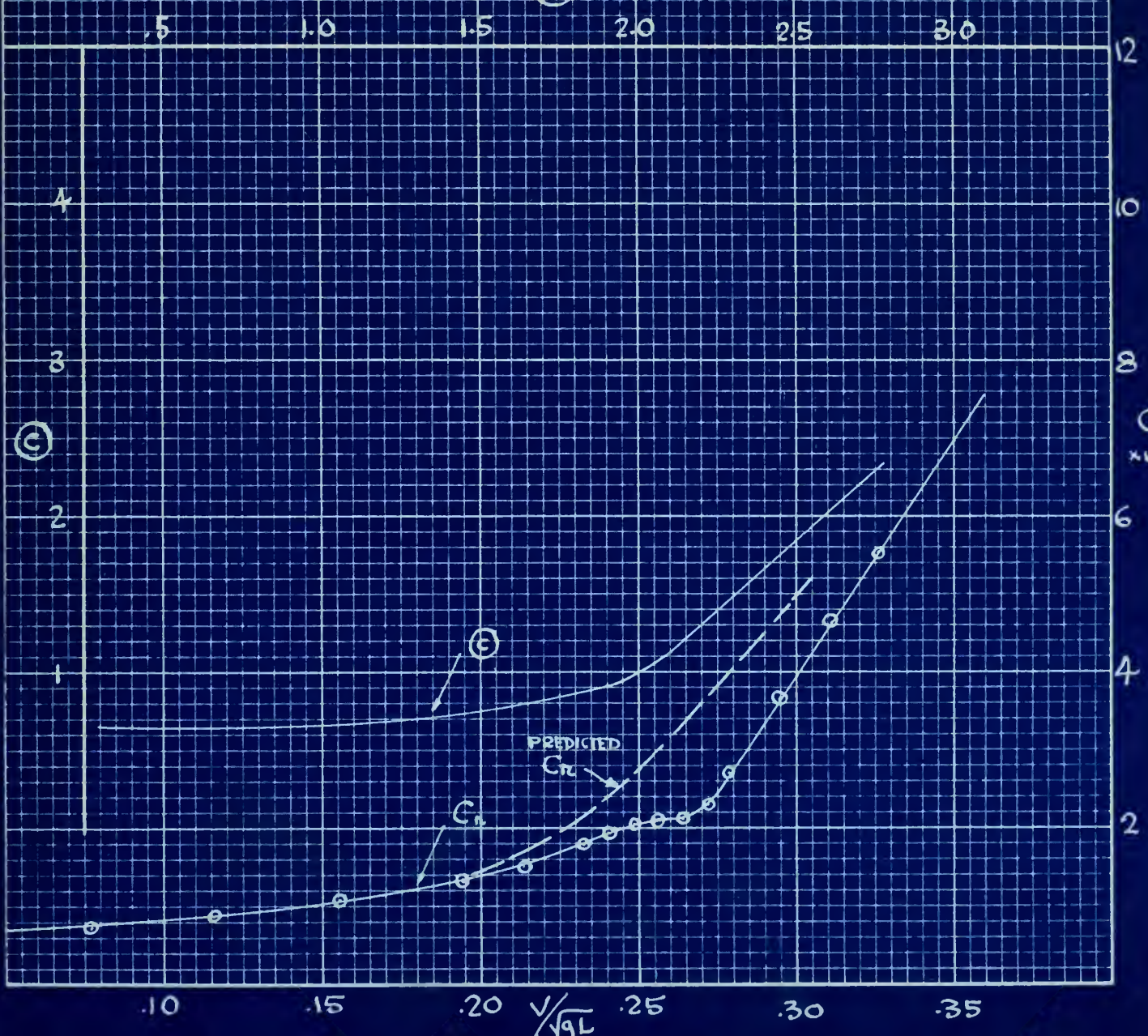


FIGURE XXXVI

MODEL NO: 3138 B

SERIAL NO: 24

 $L = 14.2'$ $B = 3.428'$ $H = 1.352'$ $\Delta = 2153 \#$ $S = 57.24 \text{ ft}$ $L/B = 4.15$ $B/H = 2.54$ $C_p = .619$ $\nabla/w^3 = 12.10$ $C_x = .850$ $C_b = .524$ $C_{pv} =$ $C_w =$ $C_{sw} = 2.68$

MODEL DATA

TEMP: 68°F

V_w	R_s
1.00	1.69
1.50	1.57
2.00	1.51
2.50	1.46
3.00	1.42
3.50	1.38
4.00	1.35
4.50	1.32
5.00	1.29
5.50	1.26
6.00	1.24
6.50	1.21
7.00	1.19
7.50	1.17
8.00	1.15
8.50	1.13
9.00	1.11
9.50	1.09
10.00	1.07
10.50	1.05
11.00	1.03
11.50	1.01
12.00	0.99
12.50	0.97
13.00	0.95
13.50	0.93
14.00	0.91
14.50	0.89
15.00	0.87
15.50	0.85
16.00	0.83
16.50	0.81
17.00	0.79
17.50	0.77
18.00	0.75
18.50	0.73
19.00	0.71
19.50	0.69
20.00	0.67
20.50	0.65
21.00	0.63
21.50	0.61
22.00	0.59
22.50	0.57
23.00	0.55
23.50	0.53
24.00	0.51
24.50	0.49
25.00	0.47
25.50	0.45
26.00	0.43
26.50	0.41
27.00	0.39
27.50	0.37
28.00	0.35
28.50	0.33
29.00	0.31
29.50	0.29
30.00	0.27
30.50	0.25
31.00	0.23
31.50	0.21
32.00	0.19
32.50	0.17
33.00	0.15
33.50	0.13
34.00	0.11
34.50	0.09
35.00	0.07
35.50	0.05
36.00	0.03
36.50	0.01
37.00	0.00
37.50	0.00
38.00	0.00
38.50	0.00
39.00	0.00
39.50	0.00
40.00	0.00
40.50	0.00
41.00	0.00
41.50	0.00
42.00	0.00
42.50	0.00
43.00	0.00
43.50	0.00
44.00	0.00
44.50	0.00
45.00	0.00
45.50	0.00
46.00	0.00
46.50	0.00
47.00	0.00
47.50	0.00
48.00	0.00
48.50	0.00
49.00	0.00
49.50	0.00
50.00	0.00
50.50	0.00
51.00	0.00
51.50	0.00
52.00	0.00
52.50	0.00
53.00	0.00
53.50	0.00
54.00	0.00
54.50	0.00
55.00	0.00
55.50	0.00
56.00	0.00
56.50	0.00
57.00	0.00
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60.50	0.00
61.00	0.00
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66.50	0.00
67.00	0.00
67.50	0.00
68.00	0.00
68.50	0.00
69.00	0.00
69.50	0.00
70.00	0.00
70.50	0.00
71.00	0.00
71.50	0.00
72.00	0.00
72.50	0.00
73.00	0.00
73.50	0.00
74.00	0.00
74.50	0.00
75.00	0.00
75.50	0.00
76.00	0.00
76.50	0.00
77.00	0.00
77.50	0.00
78.00	0.00
78.50	0.00
79.00	0.00
79.50	0.00
80.00	0.00
80.50	0.00
81.00	0.00
81.50	0.00
82.00	0.00
82.50	0.00
83.00	0.00
83.50	0.00
84.00	0.00
84.50	0.00
85.00	0.00
85.50	0.00
86.00	0.00
86.50	0.00
87.00	0.00
87.50	0.00
88.00	0.00
88.50	0.00
89.00	0.00
89.50	0.00
90.00	0.00
90.50	0.00
91.00	0.00
91.50	0.00
92.00	0.00
92.50	0.00
93.00	0.00
93.50	0.00
94.00	0.00
94.50	0.00
95.00	0.00
95.50	0.00
96.00	0.00
96.50	0.00
97.00	0.00
97.50	0.00
98.00	0.00
98.50	0.00
99.00	0.00
99.50	0.00
100.00	0.00

APPENDAGES: NONE

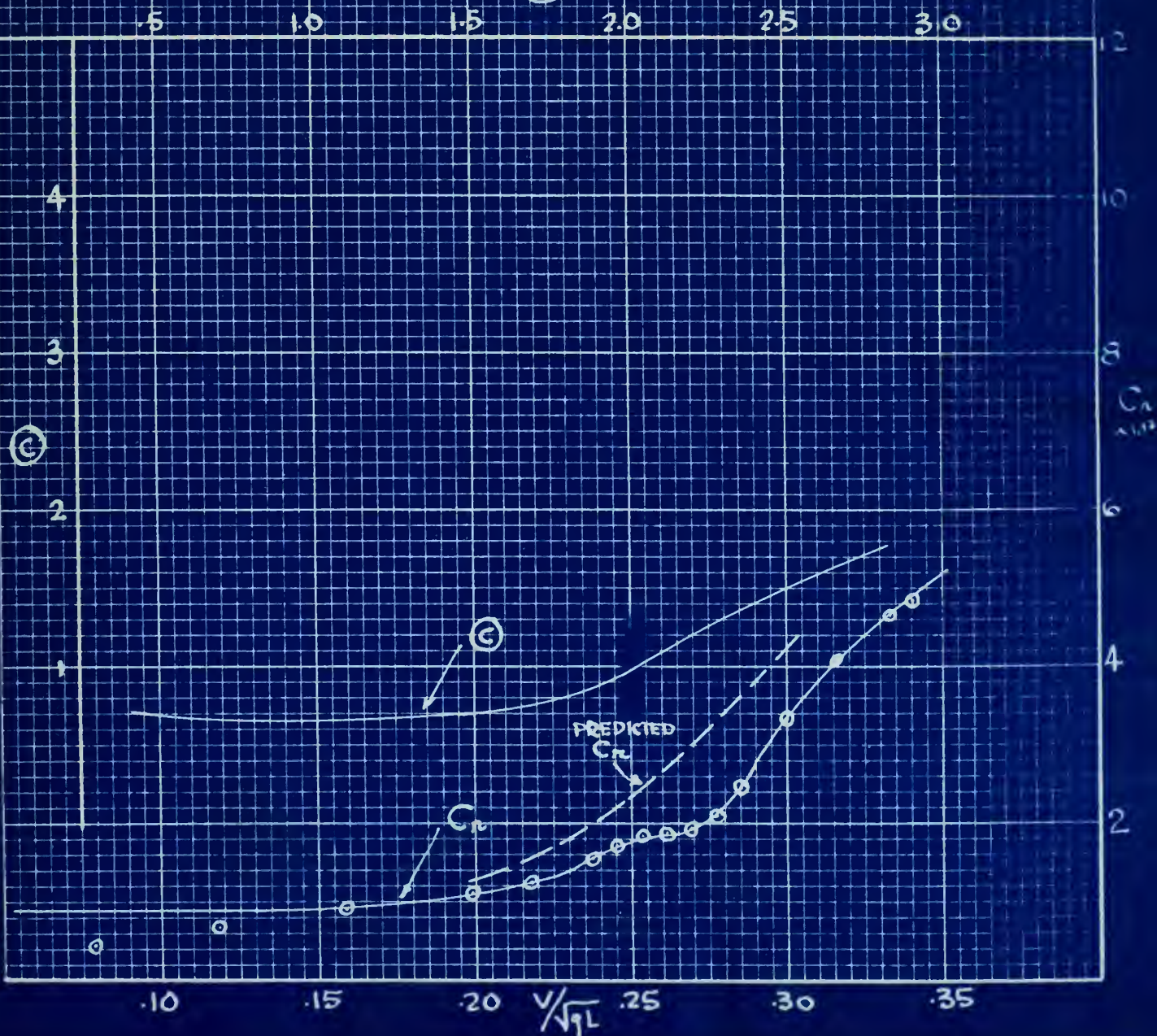
TYPE: HARBOR TUG (N)

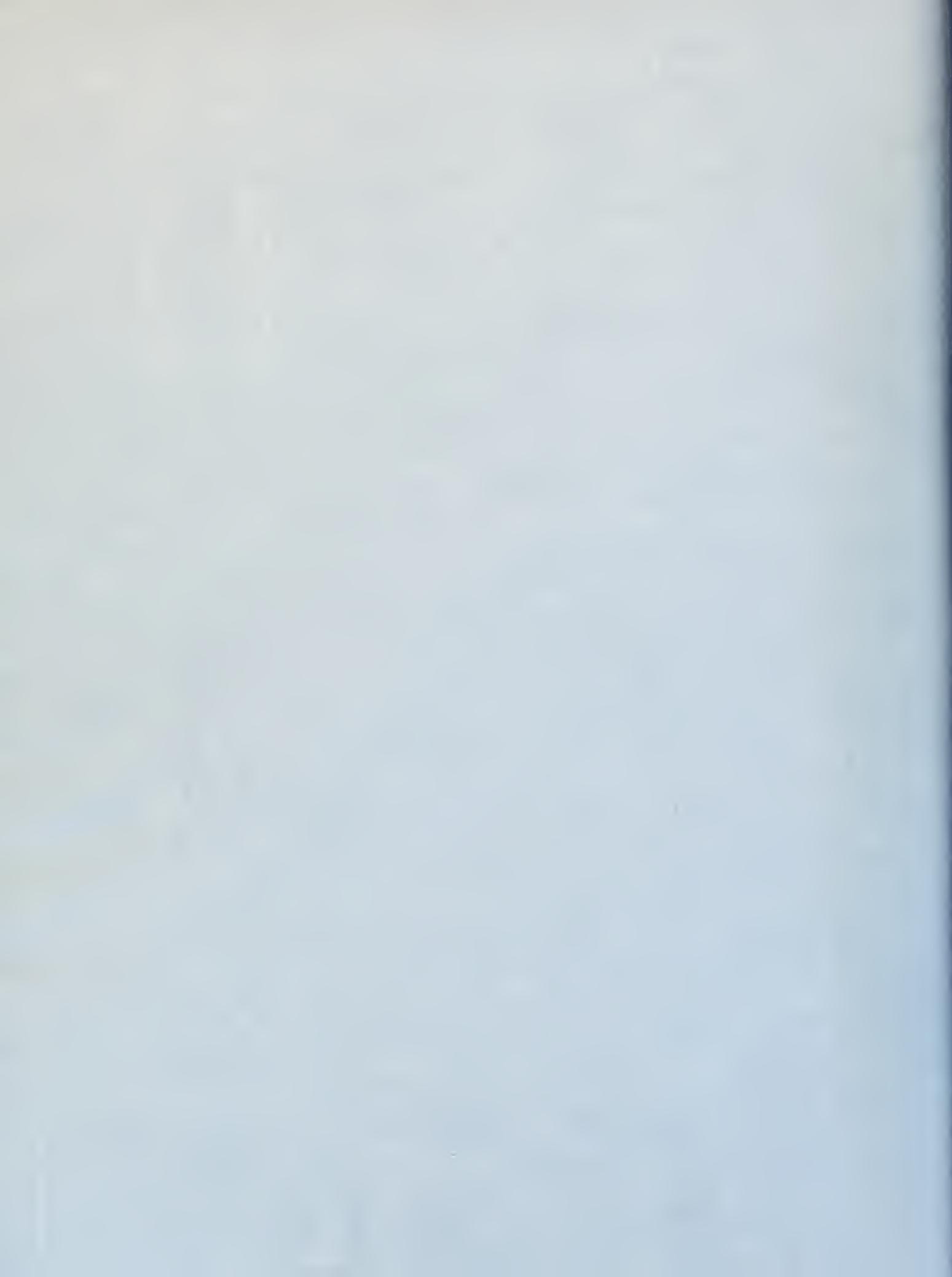
(C) vs. (K) FOR 400' SHIP

 $\Delta C_s = .0004$

TEMP = 68°F

(K)





MODEL No: 3175

SERIAL No: 25

$L = 20.0$
 $B = 3.735'$
 $H = 1.332'$
 $\Delta = 4801 \#$
 $S = 102.38$
 $L/B = 5.36$
 $B/H = 2.8$
 $C_p = .778$
 $V/(L)^3 = 9.63$
 $C_k = .996$
 $C_{dF} = .774$
 $C_{yv} = .892$
 $C_w = .865$
 $C_{sw} = 2.61$

MODEL DATA:

TEMP: 50°F.	
V_w	R_t
1.00	1.42
1.50	3.06
2.00	5.30
2.50	7.10
3.00	8.61
3.50	10.40
4.00	13.62

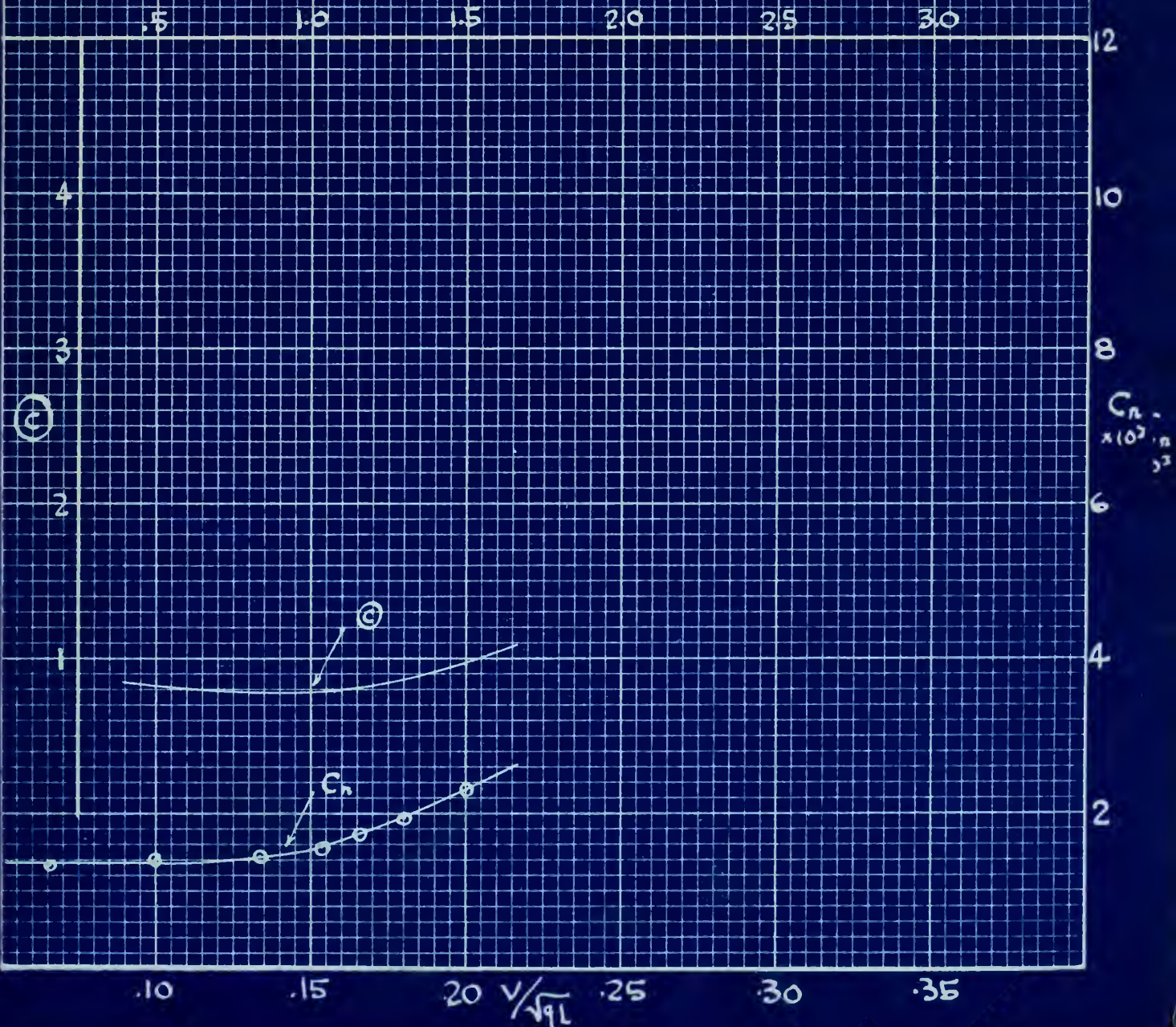
APPENDAGES: NONE - OPENINGS IN BOTTOM, HOPPER DOORS.

TYPE: HOPPER DREDGE (USAF)

Ⓒ vs Ⓐ FOR 400' SHIP

$\Delta C_s = .0004$

TEMP = 59°F



MODEL No: 3472

SERIAL No: 26

$L = 20.0'$

$C_p = .788$

$B = 3.734'$

$\frac{V}{(H)}^3 = 9.65$

$H = 1.333'$

$\Delta = 4815 \text{ #}$

$C_x = .984$

$S = 104.027 \text{ #}$

$C_b = .775$

$L/B = 5.36$

$C_{p1} = .919$

$B/H = 2.80$

$C_{w1} = .842$

$C_{sw} = 2.65$

MODEL DATA

TEMP: 56°F

V_n	R_t
1.00	1.58
1.50	3.47
2.00	6.00
2.50	7.88
2.70	9.26
2.70	10.88
3.00	14.18
3.10	15.70

APPENDAGES: BOSSING, HUB, FAIRWATER.

TYPE: SEA GOING HOPPER DREDGE (S.A.E.)

③ vs ④ FOR 400' SHIP

$\Delta C_s = .0004$

TEMP = 59°F.

④

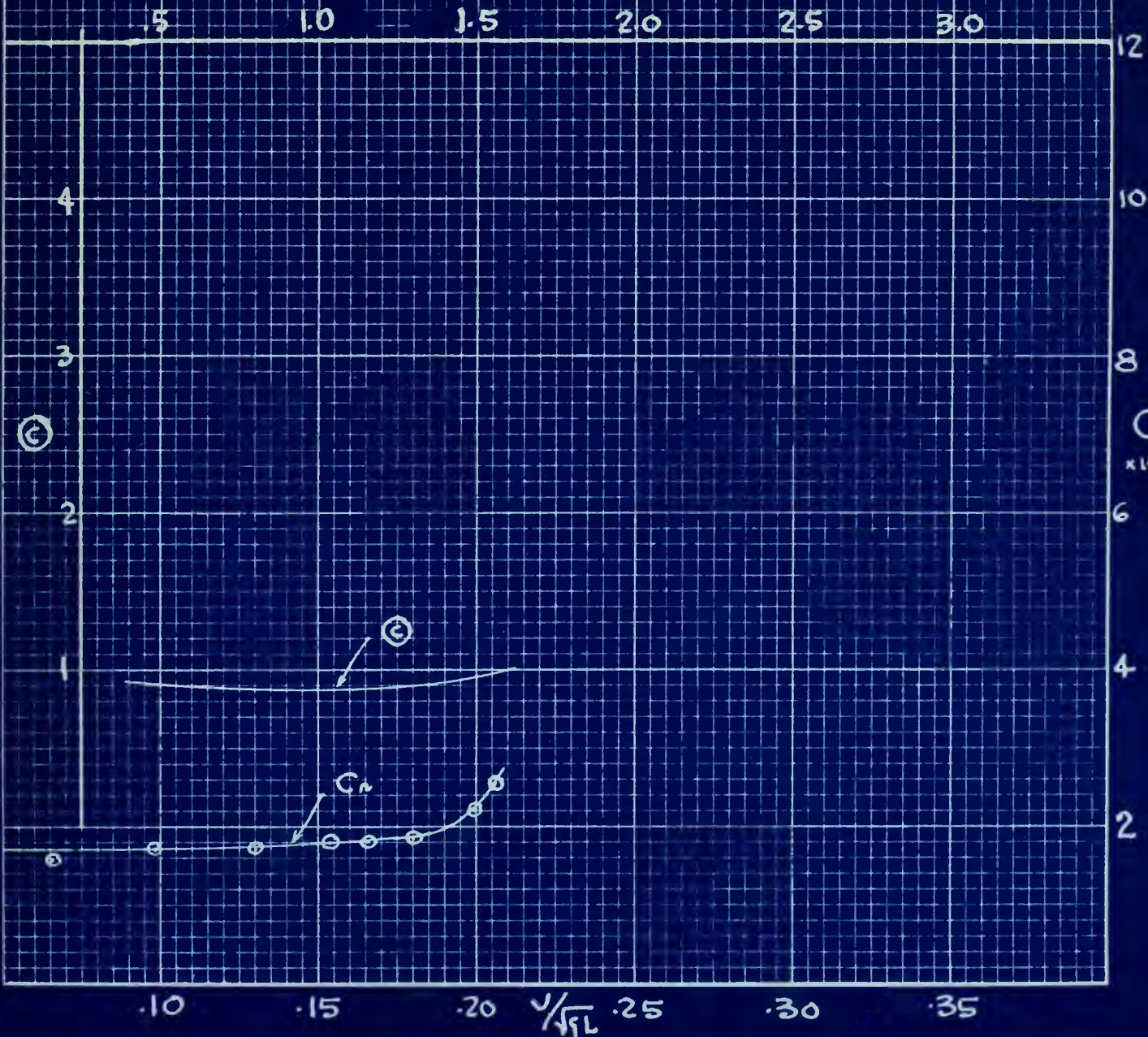


FIGURE XXXIX

MODEL No: 3486

SERIAL No: 27

 $L = 14.625'$ $B = 3.50'$ $H = 1.625'$ $\Delta = 2591 \text{ lb}$ $S = 66.587 \text{ ft}$ $L/B = 4.18$ $B/H = 2.15$ $C_F = .600$ $\nabla / (LH^3) = 13.20$ $C_A = .834$ $C_B = .498$ $C_W = .676$ $C_M = .737$ $C_{SN} = 2.70$

MODEL DATA

TEMP: 74.15 F.

V_{∞}	R_T
1.00	1.70
1.50	1.65
2.00	3.00
2.30	4.00
2.50	4.80
2.70	5.12
3.00	7.44
3.30	9.65
3.50	11.78
3.70	15.15
4.00	19.70
4.20	22.95
4.40	26.70
4.50	31.50

APPENDAGES: BAR KEEL

TYPE: YARD TUG (H.)

© vs (K) FOR 400' SHIP

 $\Delta C_F = .0004$

TEMP: 59° F

(K)

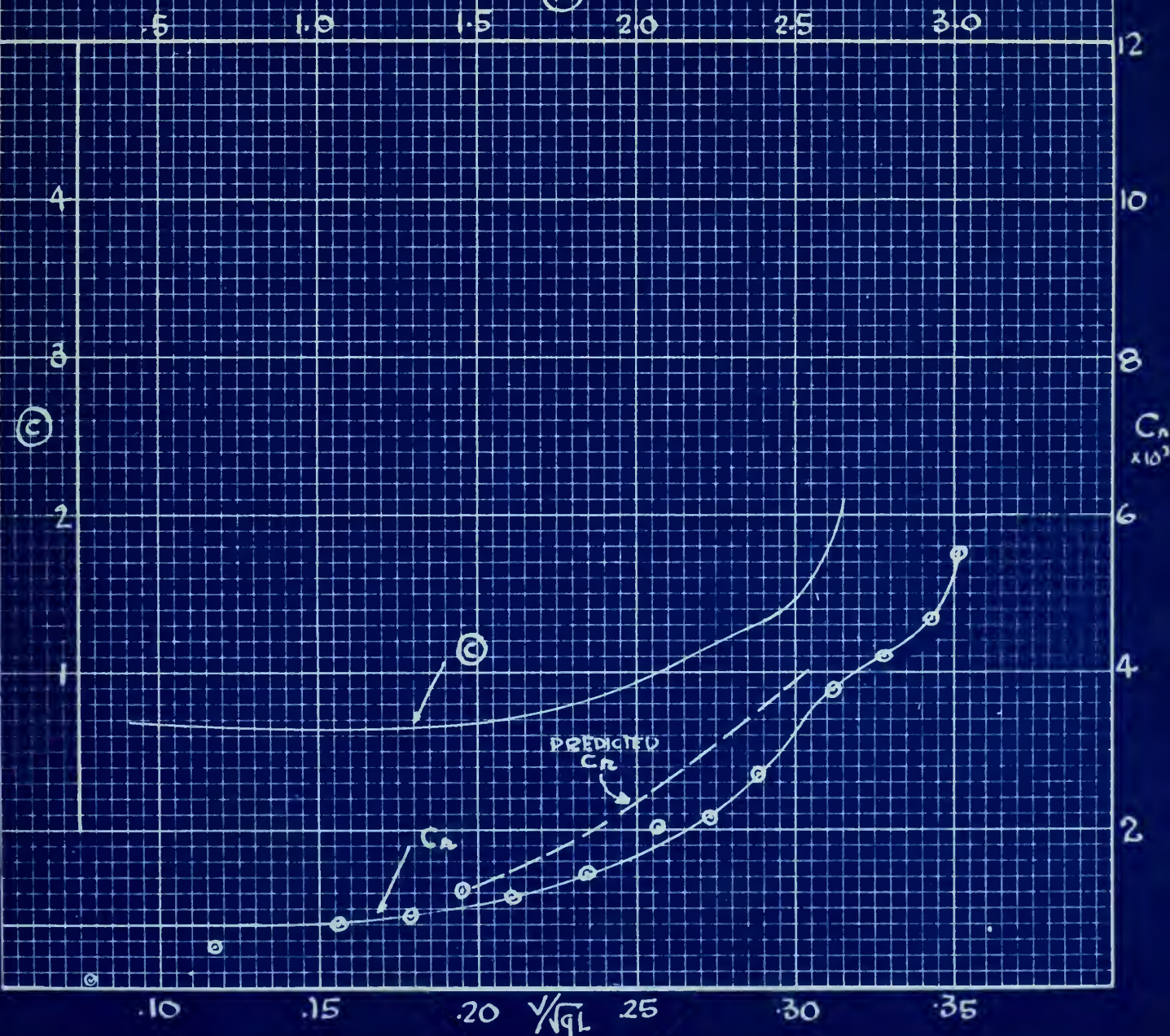


FIGURE XL

MODEL NO: 3498

SERIAL NO: 28

$L = 16.0'$
 $B = 3.779'$
 $H = 1.437' \text{ (34.185)} \quad \nabla / (L^3) = 9.29$
 $\Delta = 2375 \text{ #}$
 $S = 66.226 \text{ ft}$
 $L/B = 4.24$
 $B/H = 2.63$

 $C_F = .580$ $C_x = .757$ $C_b = .438$ $C_M = .602$ $C_W = .726$ $C_{SW} = 2.69$

MODEL DATA

TEMP: 59°F

V_x	R_T
1.00	1.84
1.50	1.75
2.00	2.03
2.50	2.72
3.00	7.32
3.50	9.61
4.00	11.48
4.50	13.87
5.00	19.67
5.50	25.35
6.00	29.90
6.50	35.00
7.00	41.24
7.50	52.70
8.00	59.00
8.50	66.10

APPENDAGES: RUDDER & PROP HUB,
 TYPE: HARBOR CUTTER (C.G.)

③ vs ④ FOR 400 SWIP

 $\Delta C_F = .0004$

TEMP = 59°F

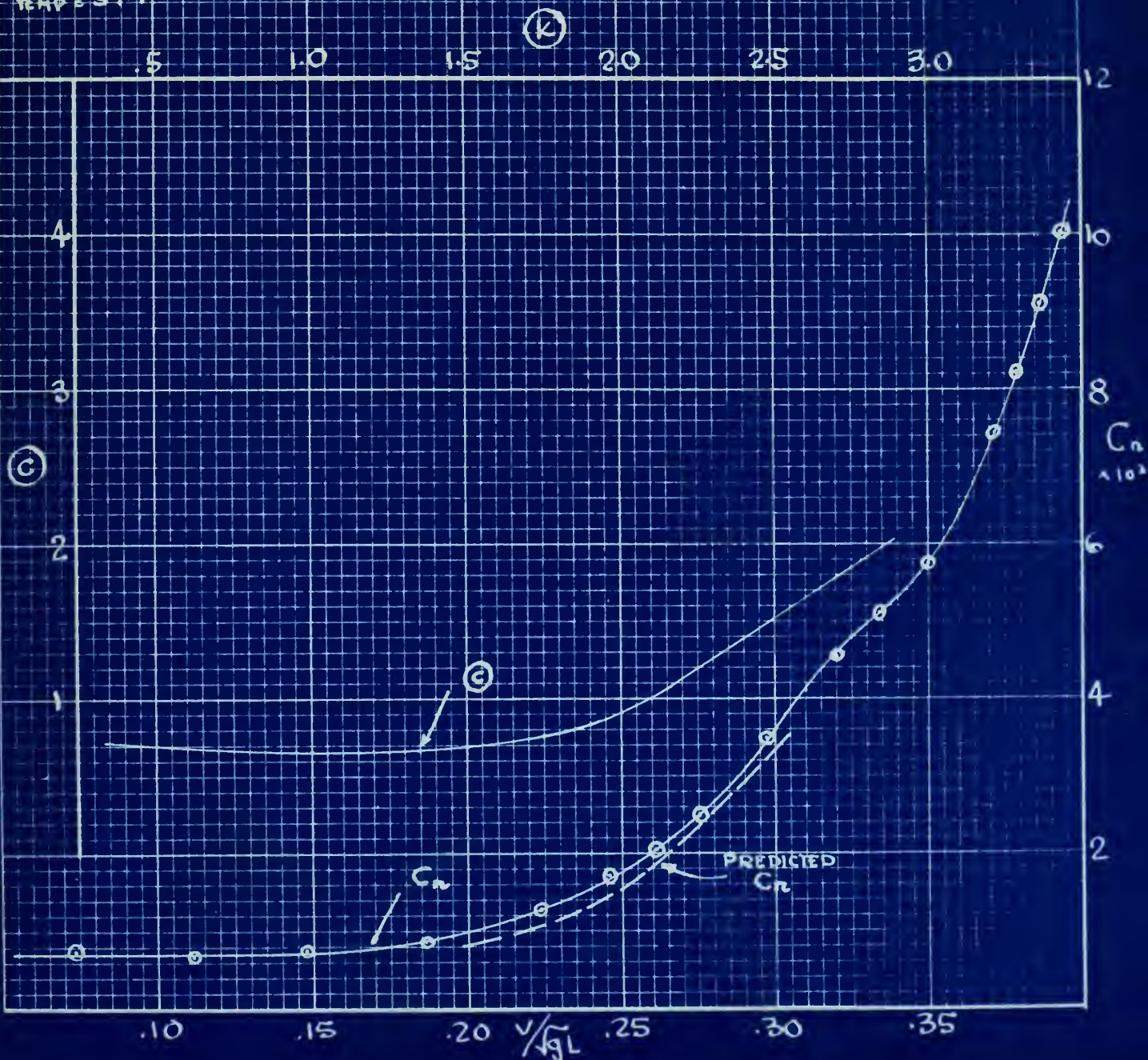


FIGURE XLI

MODEL No: 3685

SERIAL No: 29

L = 20.363'

$C_p = .749$

B = 3.364'

$\nabla / (L^3) = 8.62$

H = 1.436' ft

$C_k = .989$

$\Delta = 4520 \#$

$C_b = .741$

S = 101.712'

L/B = 6.04

$C_{pv} = .908$

B/H = 2.35

$C_w = .814$

$C_{sw} = 2.65$

MODEL DATA

TEMP: 72°F

V_k	R_T
1.00	1.13
1.30	1.81
1.50	2.43
1.70	3.03
2.00	4.21
2.30	5.55
2.50	6.60
2.70	7.80
3.00	9.86
3.20	11.85
3.40	15.37
3.50	19.64
3.60	19.96
3.80	22.70
3.90	22.22

APPENDAGES: RUBBER,

TYPE: (M)

(C) vs (K) FOR 400' SHIP

$\Delta C_{50} = 0.004$

TEMP: 59°F

(K)

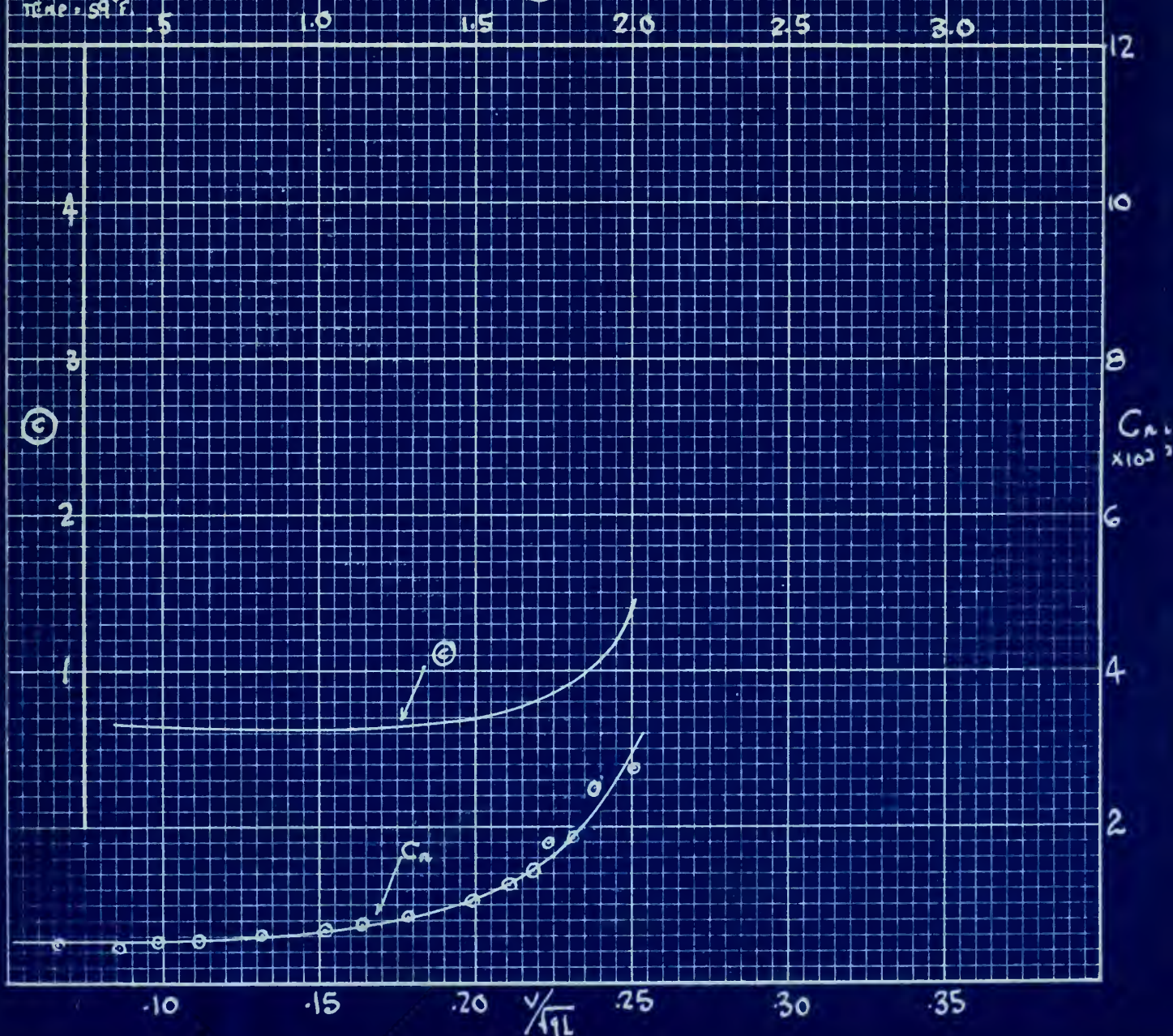




FIGURE XLII

MODEL No: 3703

SERIAL No: 30

$L = 16.54'$

$C_p = .623$

MODEL DATA.

$B = 3.454'$

$V_{(H)} = 9.59$

TEMP: 55°F

$H = 1.423' \text{ (TWIN)}$

 V_R

$\Delta = 2716 \text{ #}$

$C_{x+} = .859$

 R_T

$S = 75.513 \text{ N}$

$C_b = .535$

1.00

$L/B = 4.80$

$C_{pv} = .686$

1.50

$B/H = 2.42$

$C_{wt} = .719$

1.70

$C_{sw} = 2.82$

2.00

2.40

2.70

3.00

3.30

3.60

3.90

4.20

4.40

4.50

APPENDAGES: CONTRA STERN POST & RUDDER

TYPE: SEA GOING TUG (M)

C vs K FOR 400' SHIP

 $\Delta C_S = .0004$

TEMP: 54°F

(K)

(C)

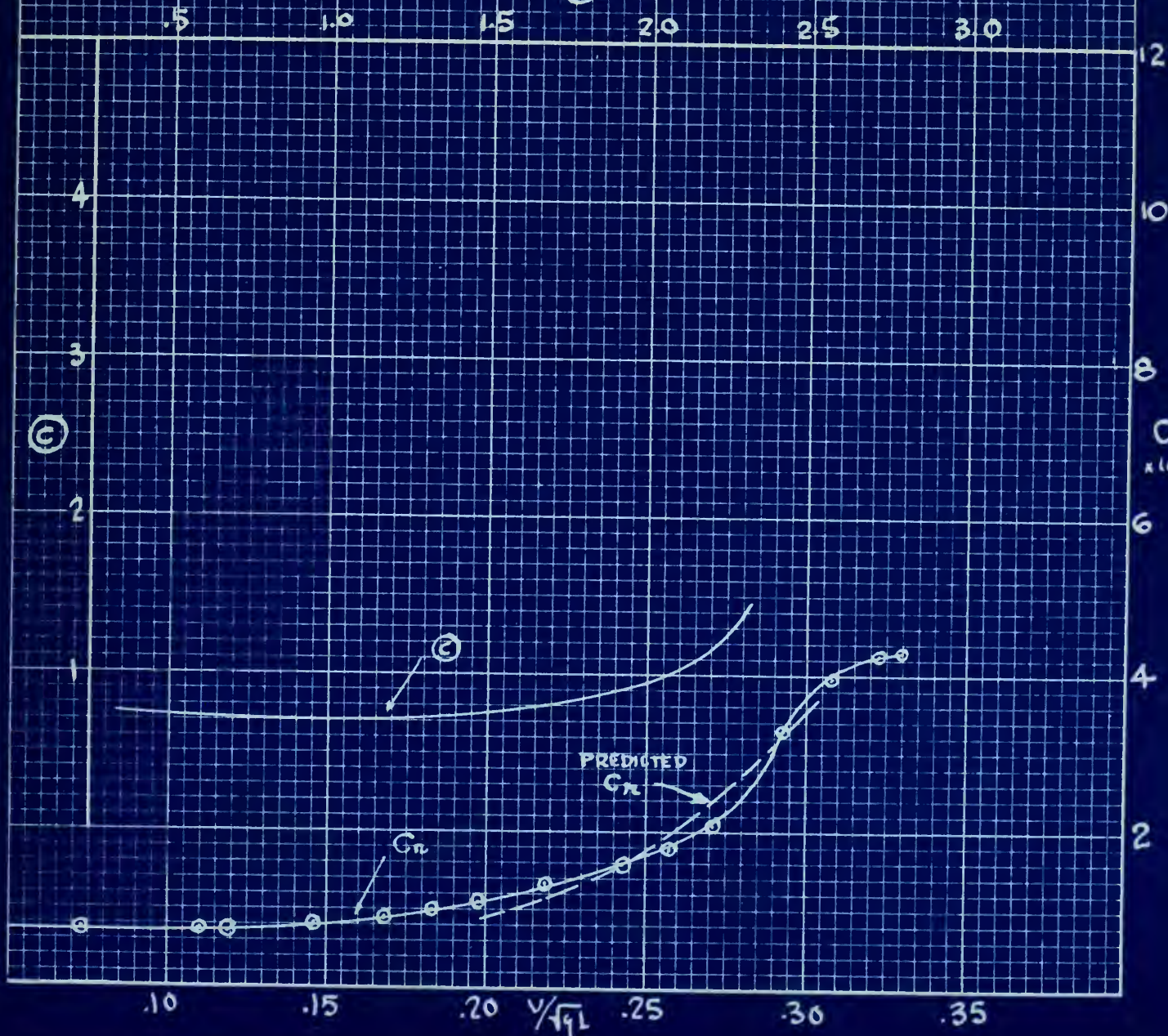
 $C_R \times 10^3$ 

FIGURE XLIII

MODEL NO: 3705

SERIAL NO: 31

 $L = 15.625'$ $C_p = .615$ $B = 3.854'$ $\nabla / (L^3) = 11.94$ $H = 1.417'$ (Des. Form) $C_{x1} = .758$ $\Delta = 28394$ $C_b = .467$ $S = 69.619$ $C_{pv} = .508$ $L/B = 4.06$ $C_w = .725$ $B/H = 2.38$ $C_{sw} = 2.61$

MODEL DATA

TEMP: 62°F

V_r	R_T
1.00	.90
1.30	1.47
1.50	1.87
1.70	2.48
2.00	3.43
2.30	4.58
2.50	5.47
2.70	6.47
3.00	8.28
3.30	10.67
3.50	13.99
3.70	16.78
4.00	24.12
4.20	28.90
4.40	33.20

APPENDAGES: RUDDER
TYPE: CUTTER (C.G.)BOW ARRANGEMENT FOR
POW PROP

C vs K FOR 400' SHIP

 $\Delta C_s = .0004$
TEMP: 59°F

(K)

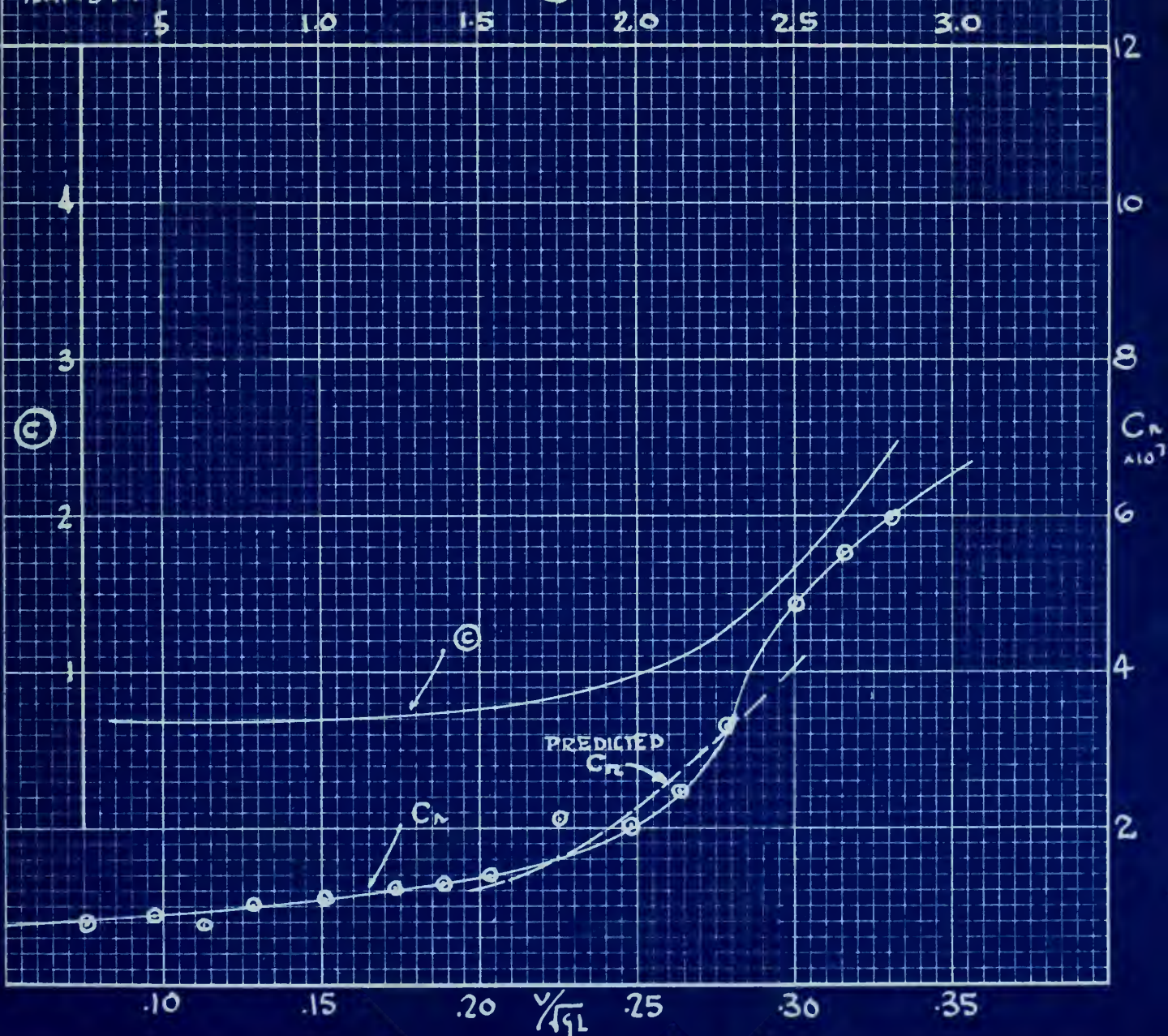




FIGURE XLIV

MODEL No: 3714

SERIAL No: 32

L = 4.86

 $C_p = .822$

B =

 $\nabla/(\Delta)^3 = 9.05$

H =

 $C_x = .950$ $\Delta = 64.86 \#$ $C_b = .781$

S = 6.221 d

L/B =

 $C_{pv} =$

B/H = 2.12

 $C_w =$ $C_{sw} = 2.77$

MODEL DATA

TEMP: 66°F

V_k	R
.3	.013
.4	.021
.5	.031
.6	.043
.7	.058
.8	.075
.9	.095
1.0	.122
1.1	.149
1.2	.180
1.3	.213
1.4	.250

APPENDAGES: NONE

TYPE: CONCRETE TANKER BARGE (M)

Ⓒ VS Ⓐ FOR 400' SHIP

 $\Delta C_s = .0007$

TEMP = 59°F

Ⓐ

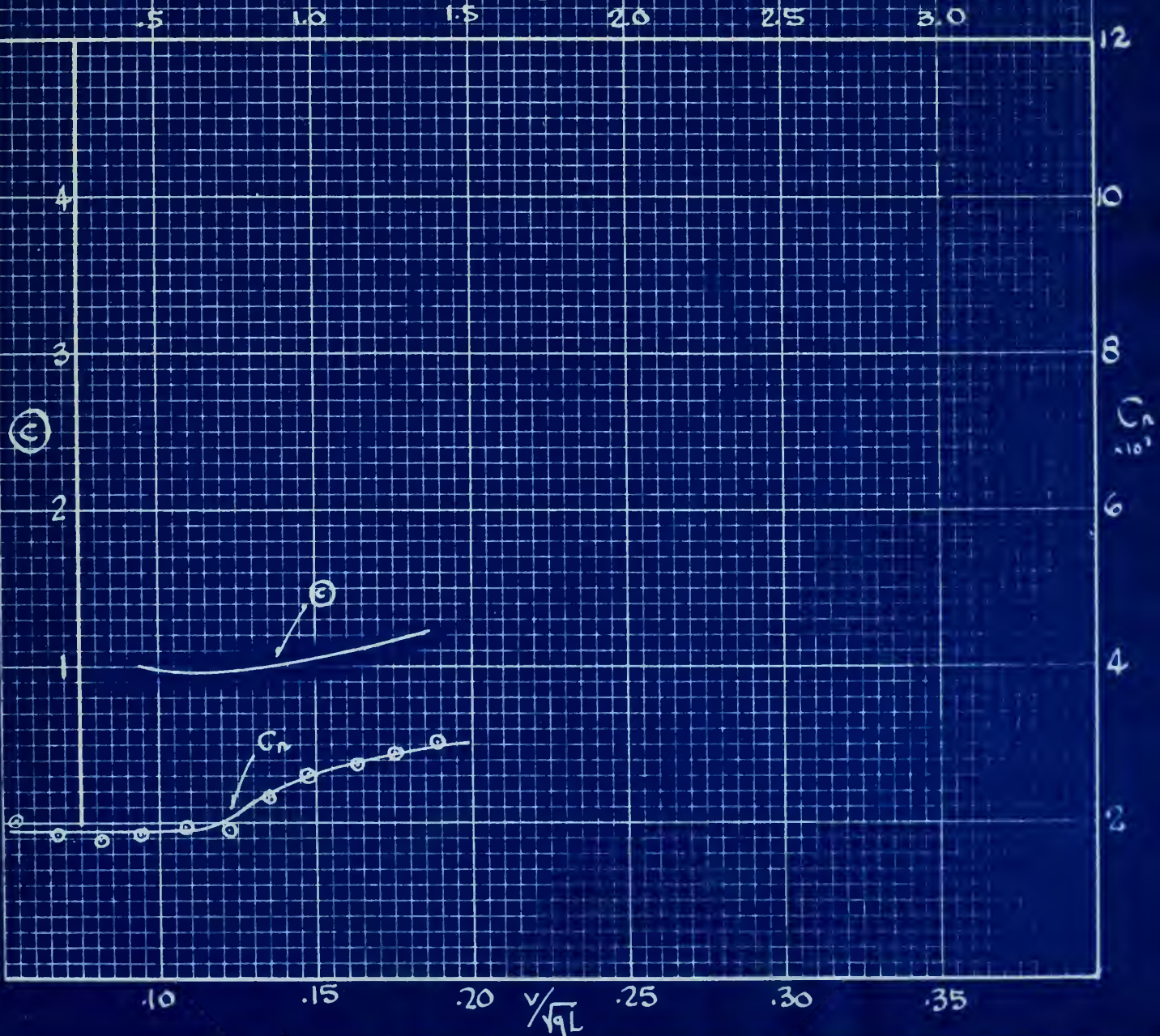


FIGURE XLV

Model No: 3725

SERIAL No: 33

$L = 16.97'$
 $B = 3.20'$
 $H = 1.196'$
 $\Delta = 2702\#$
 $S = 71.442$
 $L/B = 5.30$
 $B/H = 2.68$
 $C_D = .683$
 $\nabla/(LH)^3 = 8.90$
 $C_x = .978$
 $C_b = .668$
 $C_{pv} = .901$
 $C_w = .739$
 $C_{sw} = 2.63$

MODEL DATA:

TEMP: 55.5°F.

V_u	R_T
1.00	1.01
1.50	2.19
2.00	3.75
2.20	4.54
2.40	5.45
2.60	6.45
2.80	7.63
3.00	9.00
3.20	10.43
3.40	12.00
3.60	13.65
3.80	15.40
4.00	17.25
4.20	19.00
4.40	20.90
4.60	22.80
4.70	24.95

APPENDAGES: NONE

TYPE F.O. BARGE (N)

Ⓒ vs Ⓓ FOR 400' SHIP

$\Delta C_s = .000$

TEMP: 54°F

(K)

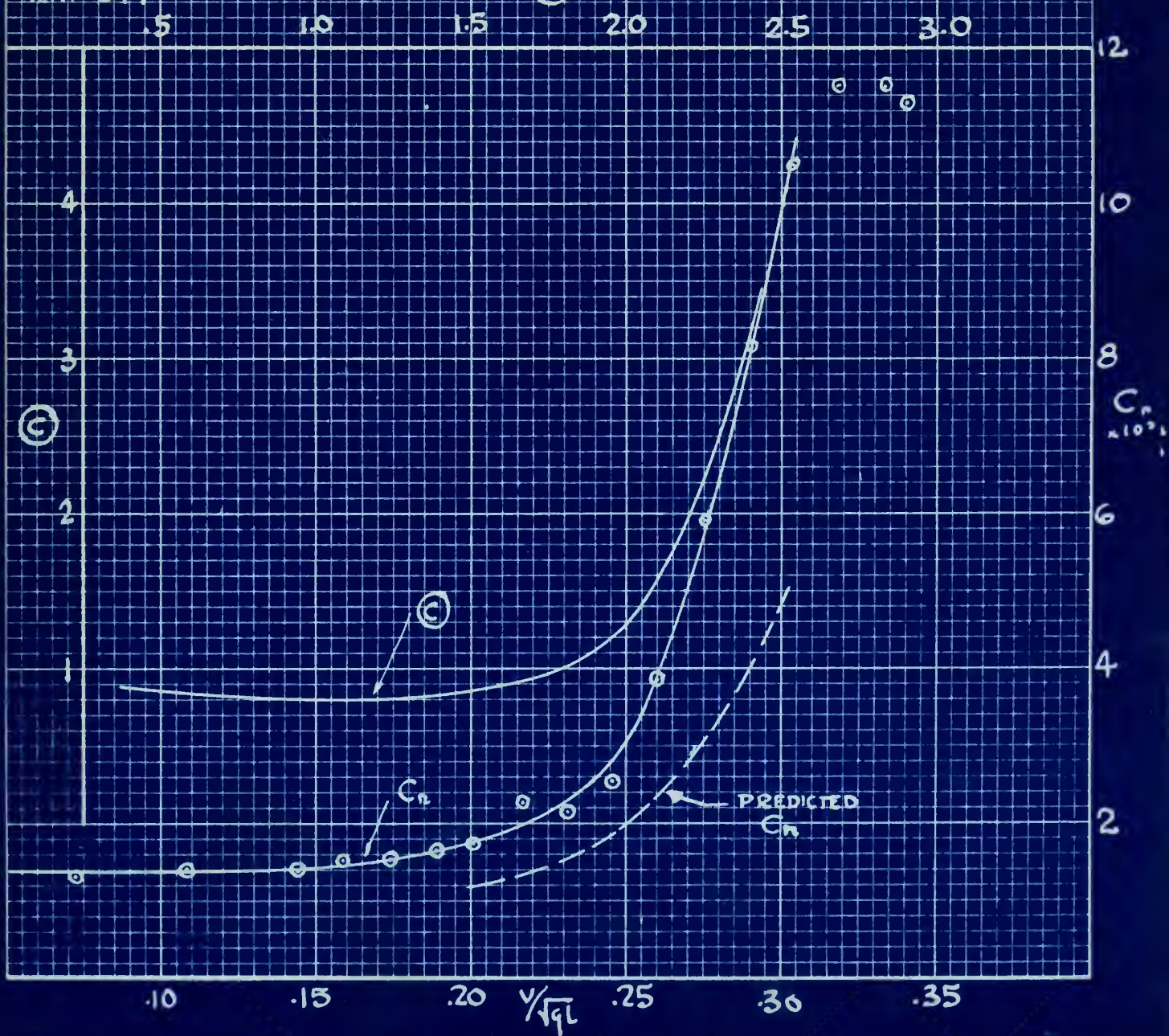


FIGURE XLVI

MODEL No: 3745

SERIAL No: 34

L = 20.335'

 $C_p = .770$

B = 3.088'

 $V/(LH)^3 = 8.56$ H = 1.50' $\pm$ $C_A = .990$ $\Delta = 4469 \#$ $C_b = .762$

S = 101.788 d

 $C_{pv} = .913$

L/B = 6.58

 $C_{wv} = .832$

B/H = 2.06

 $C_{sw} = 2.66$

MODEL DATA.

TEMP: 57° F

V_{∞}	R_T
1.0	1.20
1.5	2.55
2.0	4.13
2.2	5.18
2.4	6.14
2.6	7.21
2.8	8.41
3.0	9.83
3.1	10.68

APPENDAGES: NONE

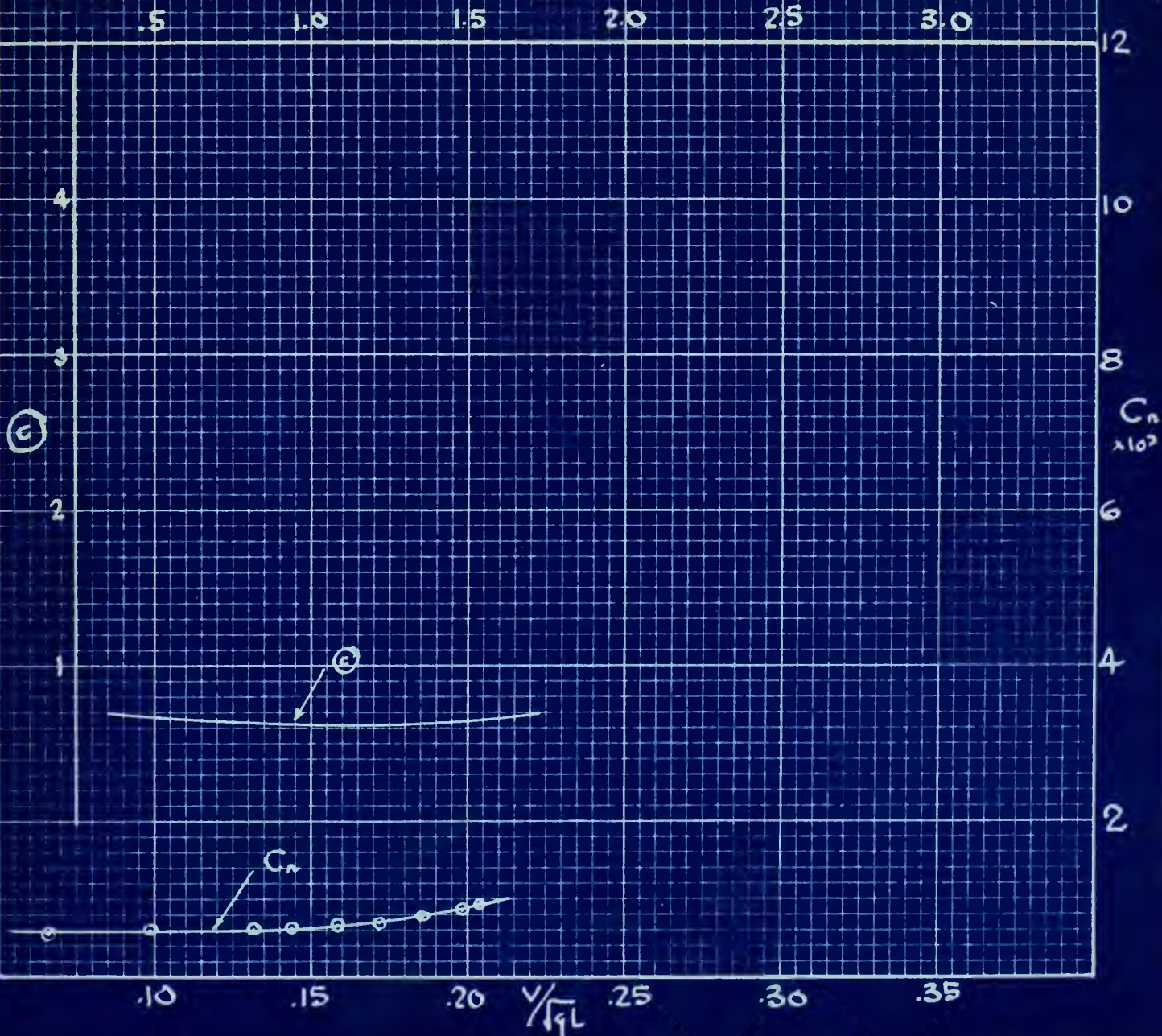
TYPE: CONCRETE BARGE (M)

(C) vs (K) FOR AOR SHIP

 $AG_s = .000 \pm$

TEMP: 59° F

(K)



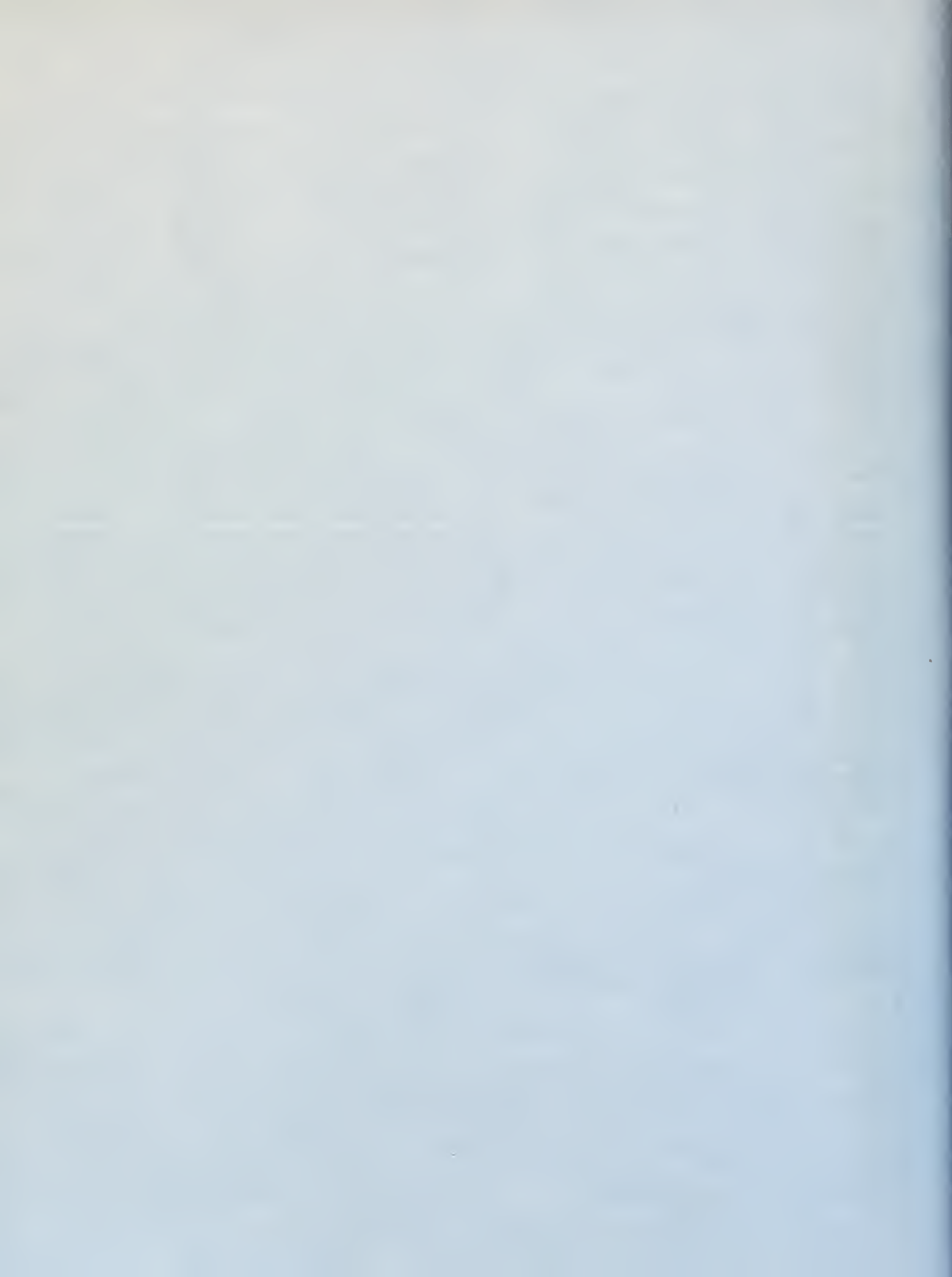


FIGURE XLVII

MODEL No: 3755

SERIAL No: 35

$L = 16.352'$
 $B = 3.506'$
 $H = 1.290'$ (DEEP DRAW)
 $\Delta = 2330 \#$
 $S = 75.28 \#$
 $L/B = 4.66$
 $B/H = 2.72$
 $C_p = .675$
 $V/(W)^2 = 8.50$
 $C_s = .749$
 $C_b = .505$
 $C_{pv} = .636$
 $C_w = .793$
 $C_{sw} = 3.06$

MODEL DATA

TEMP: 67°F

V_n	R_T
1.0	1.62
1.5	2.17
2.0	2.83
2.5	3.60
3.0	4.51
3.2	4.82
3.4	5.14
3.6	5.47
3.8	5.81
4.0	6.16
4.1	6.30
4.2	6.45
4.4	6.79
4.6	7.14
4.8	7.50
4.9	7.64

APPENDAGES: LOG KEEL, BILGE KEELS

TYPE: COSTAL MINE SWEEP (N)

© 15 (K) FOR 100' SHIP

$\Delta C_d = .0004$

TEMP: 59°F

(K)

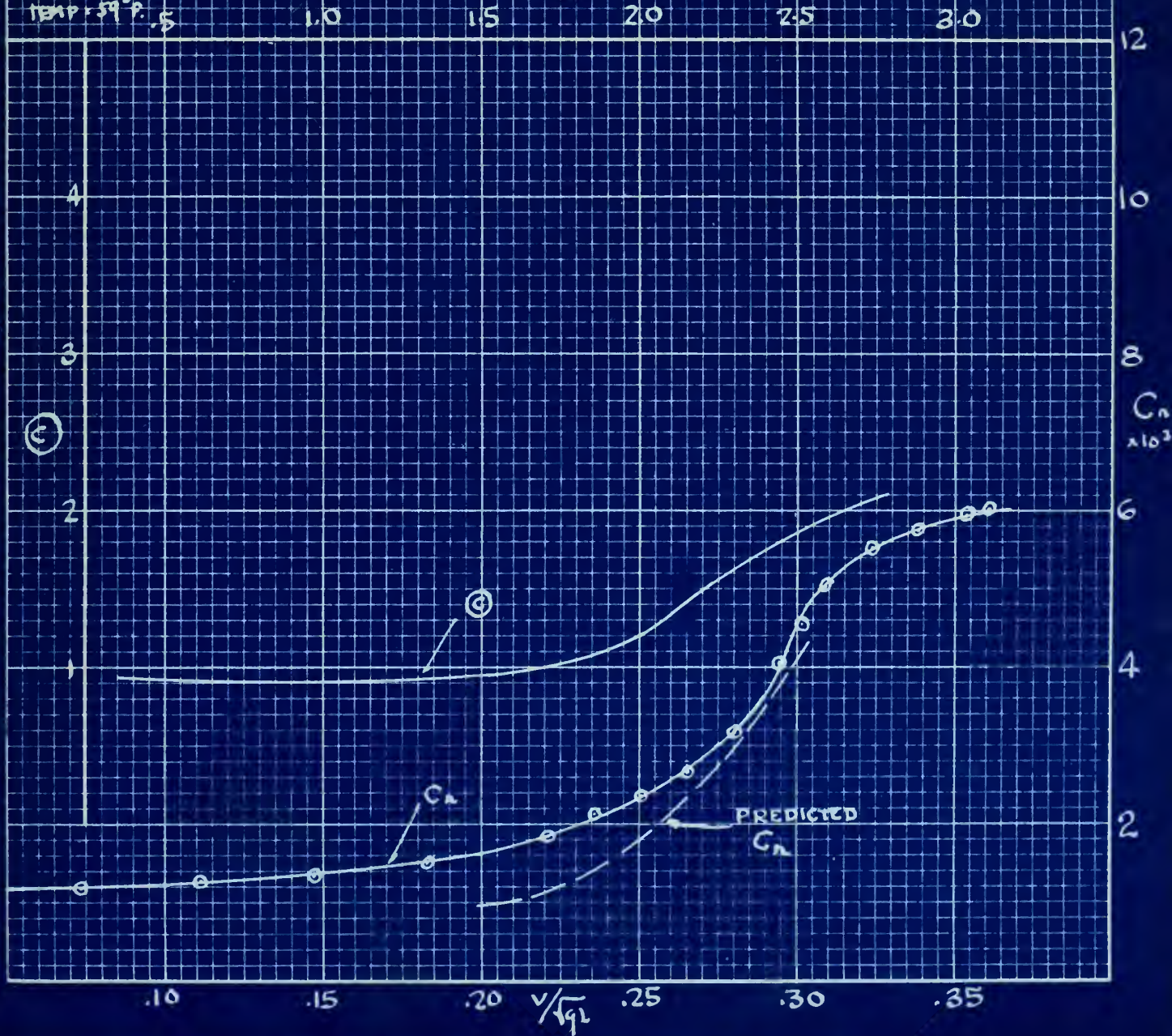


FIGURE XLVIII

MODEL No: 4085

SERIAL No: 36

 $L = 11.11'$ $B = 2.733'$ $H = 1.00'$ (DESIGN) $\Delta = 852\#$ $S = 33.909\#$ $L/B = 4.08$ $B/H = 2.733$ $C_p = .596$ $V/\sqrt{g} = 10.0$ $C_x = .757$ $C_b = .451$ $C_{pv} = .622$ $C_w = .738$ $C_{sw} = 2.75$

MODEL DATA.

TEMP: 73°F.

V_K	R_T
1.00	.15
1.50	.49
1.75	1.35
2.00	1.77
2.25	2.28
2.50	2.90
2.75	3.77
3.00	4.91
3.25	6.44
3.50	8.79
3.75	10.50
4.00	13.25
4.25	15.01
4.50	17.05
4.75	19.50
5.00	22.65
5.25	26.80

APPENDAGES: RUDDER

TYPE: TUG (USAE)

③ VS ② FOR 400' SHIP

 $\Delta C_p = .0004$

TEMP = 54°F.

②

③

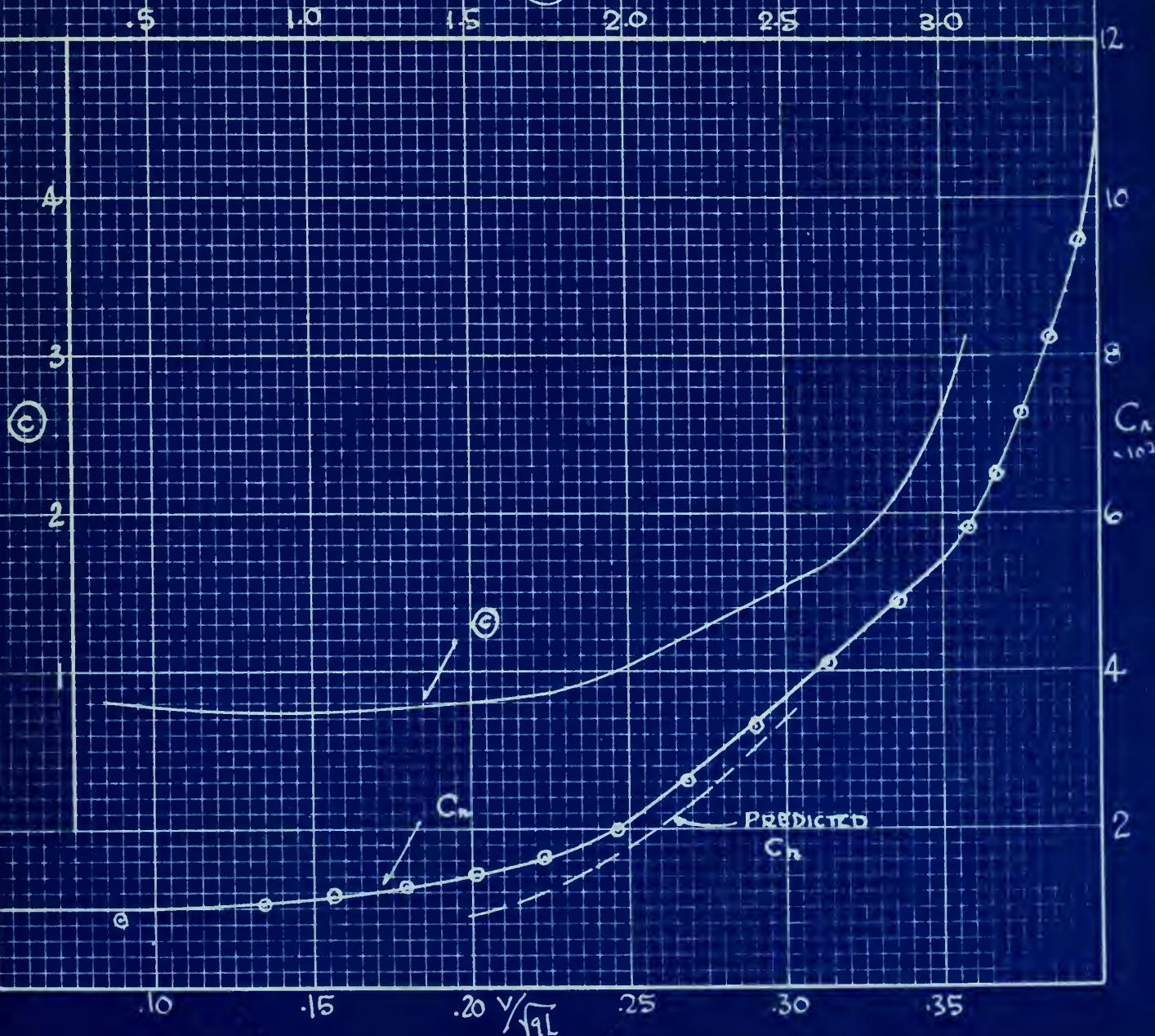




FIGURE ALIX

MODEL NO: 4086

SERIAL NO: 37

L = 11.11'

 $C_p = .615$

B = 2.620'

 $\nabla/L^3 = 12.23$

H = 1.072' (DESIGN)

 $C_x = .876$ $\Delta = 1048 \text{ M}$ $C_b = .538$

S = 37.226 d

 $C_{wv} = .711$

L/B = 4.24

 $C_{wv} = .758$

B/H = 2.442

 $C_{sw} = 2.73$

APPENDAGES: RUDDER,

TYPE: TUG (USAE)

MODEL DATA

TEMP: 64°F

V_K	R_T
1.000	1.60
1.406	1.04
1.755	1.48
2.000	1.80
2.300	2.58
2.600	3.39
2.800	4.05
3.005	5.24
3.203	6.36
3.410	8.72
3.600	10.60
3.800	12.35
3.905	13.50
4.000	14.85
4.105	16.85
4.210	19.46
4.300	22.60
4.400	26.65

C vs K FOR 400' SHIP

 $\Delta C_f = .0004$

TEMP: 59°F

(K)

(C)

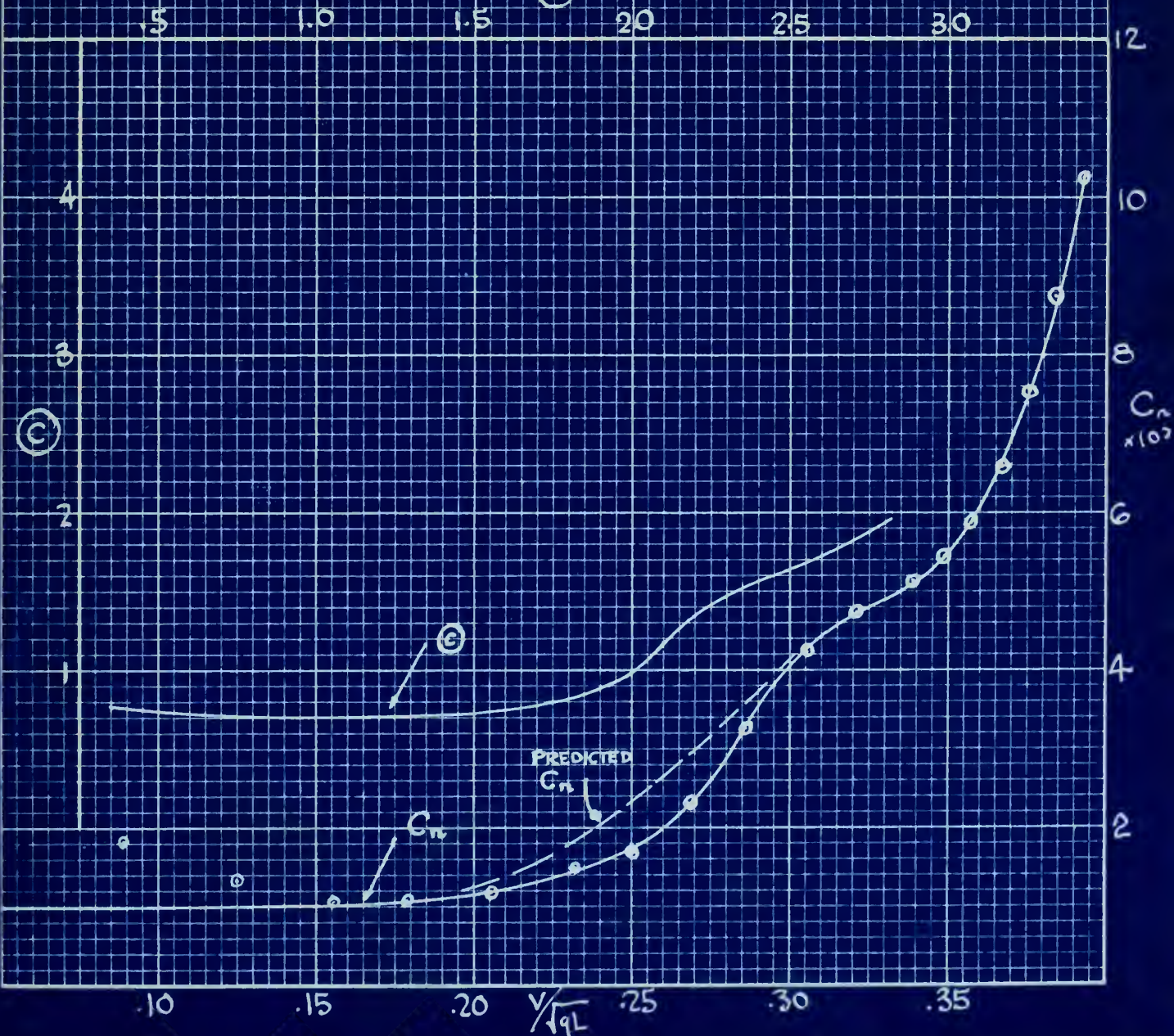


FIGURE I

MODEL No: 4087

SERIAL No: 38

$L = 11.11'$

$C_p = .583$

$B = 3.40'$

$\nabla / (LH)^3 = 15.17$

$H = 1.18'$ (DES. SHIP)

$C_x = .801$

$\Delta = 1297 \#$

$C_b = .467$

$S = 46.5 \#$

$C_{pv} = .626$

$L/B = 3.27$

$C_w = .745$

$B/H = 2.88$

$C_{sw} = 3.06$

MODEL DATA

TEMP: 73°F

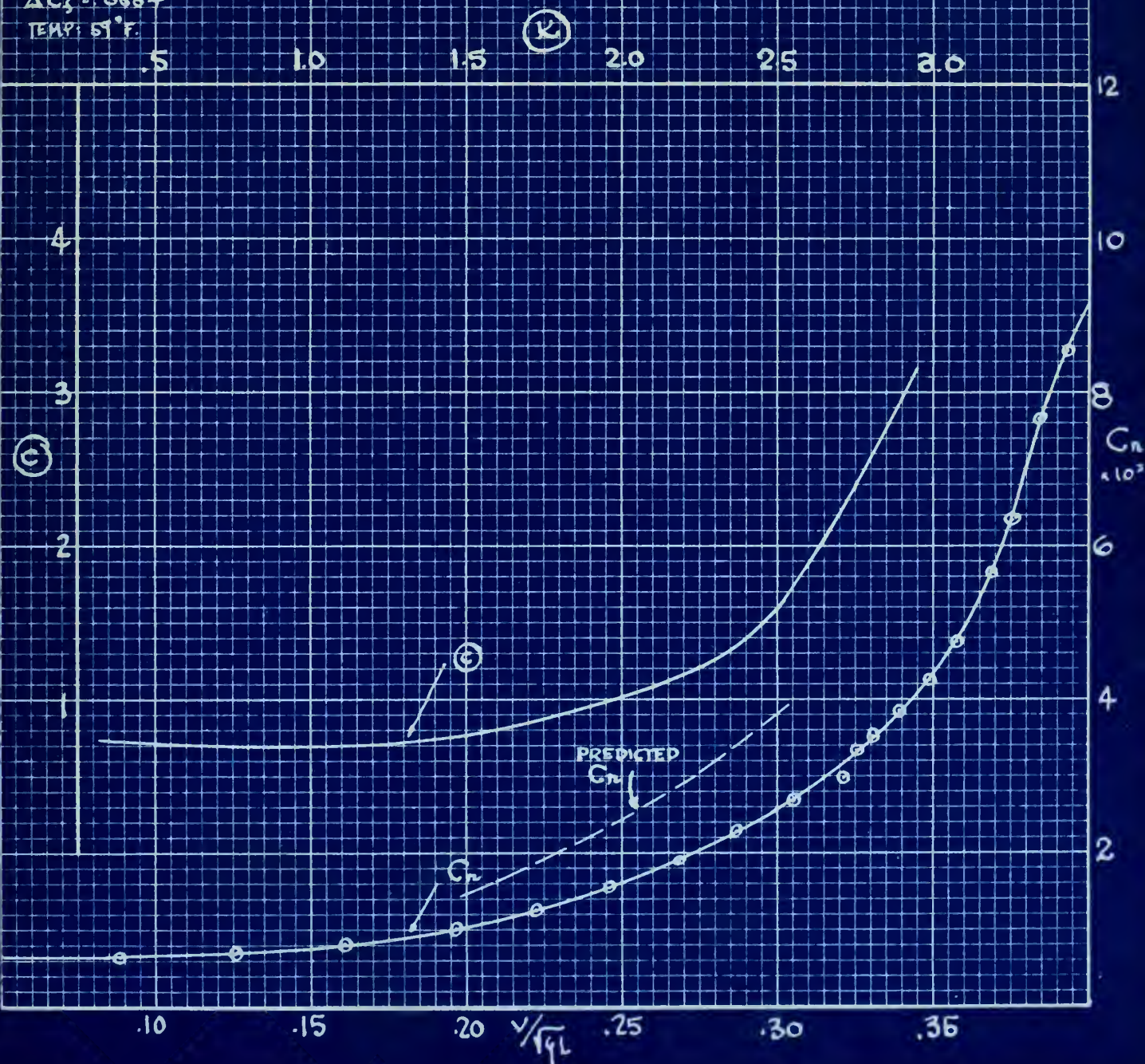
V_u	R_t	CORRECTED FOR TURBULENT FLOW
1.01	.598	
1.04	1.112	
1.50	1.897	
2.205	2.750	
2.50	3.480	
2.75	4.70	
3.00	5.92	
3.20	7.17	
3.41	8.78	
3.60	10.52	
3.70	11.70	
3.80	12.85	
3.89	14.20	
4.00	16.10	
4.12	19.00	
4.21	21.41	
4.30	25.37	
4.40	28.85	

APPENDAGES: RUDDER (SAND STRIP TURB. IND.)
TYPE: TUG (USAE)

(C) VS (K) FOR 400' SHIP

$\Delta C_s = .0004$

TEMP: 59°F



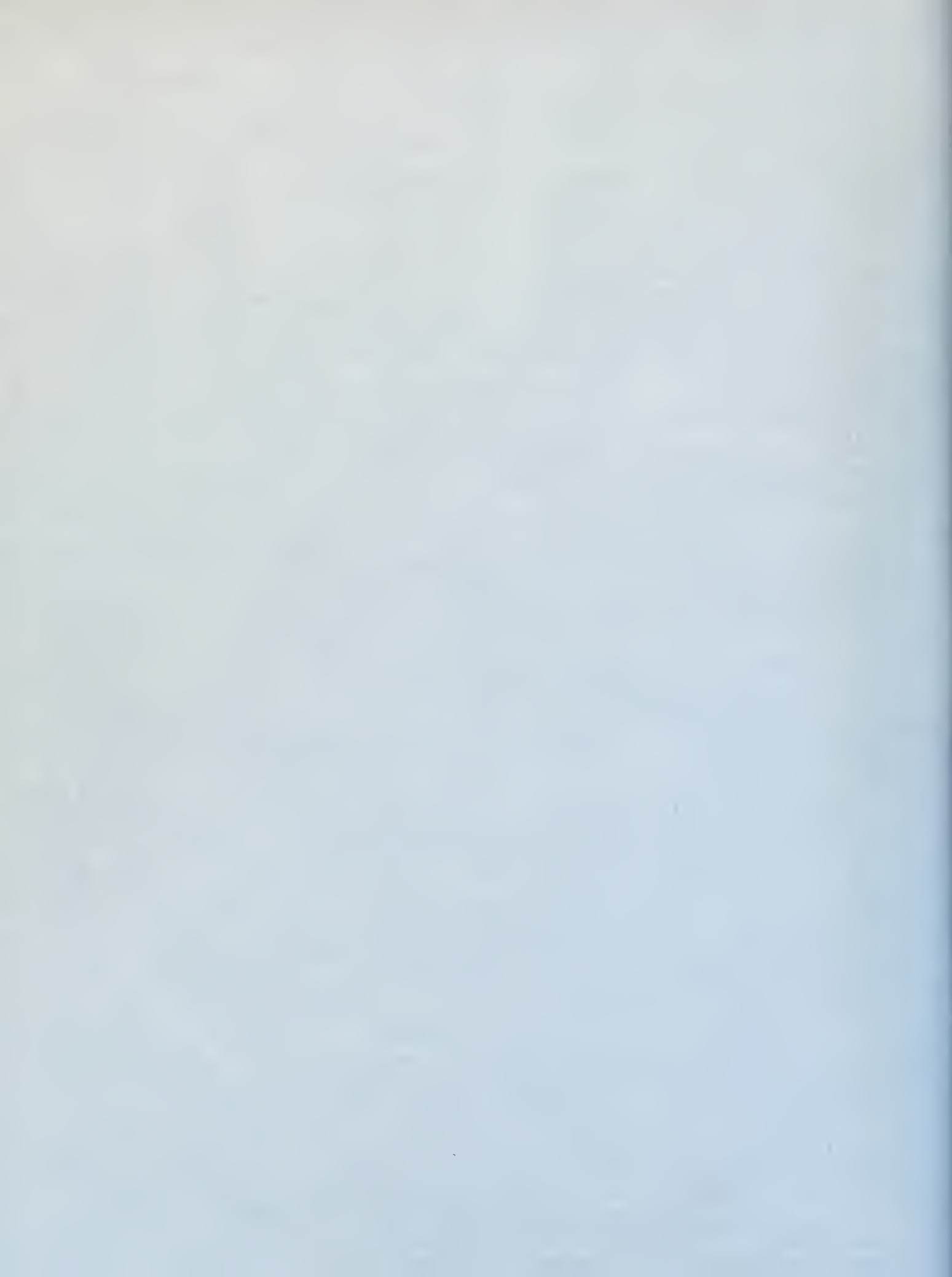


FIGURE II

MODEL No: 4088

SERIAL No: 39

$L = 11.11'$
 $B = 2.99'$
 $H = 1.278'$
 $\Delta = 1441 \#$
 $S = 44.5'$
 $L/B = 3.72$
 $B/H = 2.34$

$C_p = .623$
 $\nabla/L^3 = 16.89$
 $C_x = .8713$
 $C_b = .544$
 $C_{IV} = .701$
 $C_w = .776$
 $C_{SW} = 2.78$

MODEL DATA

TEMP: 15°F

V_k	R_t
1.00	.58
1.50	1.33
1.75	1.82
2.00	2.40
2.25	3.07
2.50	3.88
2.75	5.88
3.00	6.39
3.25	8.98
3.50	11.74
3.75	14.40
4.00	17.82
4.10	19.78
4.20	22.35
4.30	25.93
4.40	30.79
4.50	36.65

APPENDAGES: RUDDER (SAND STRIP TURB. IND.)

TYPE: TUG (USAF)

Ⓒ vs Ⓚ FOR 400' SHIP

$\Delta C_L = .0004$

TEMP = 59°F.

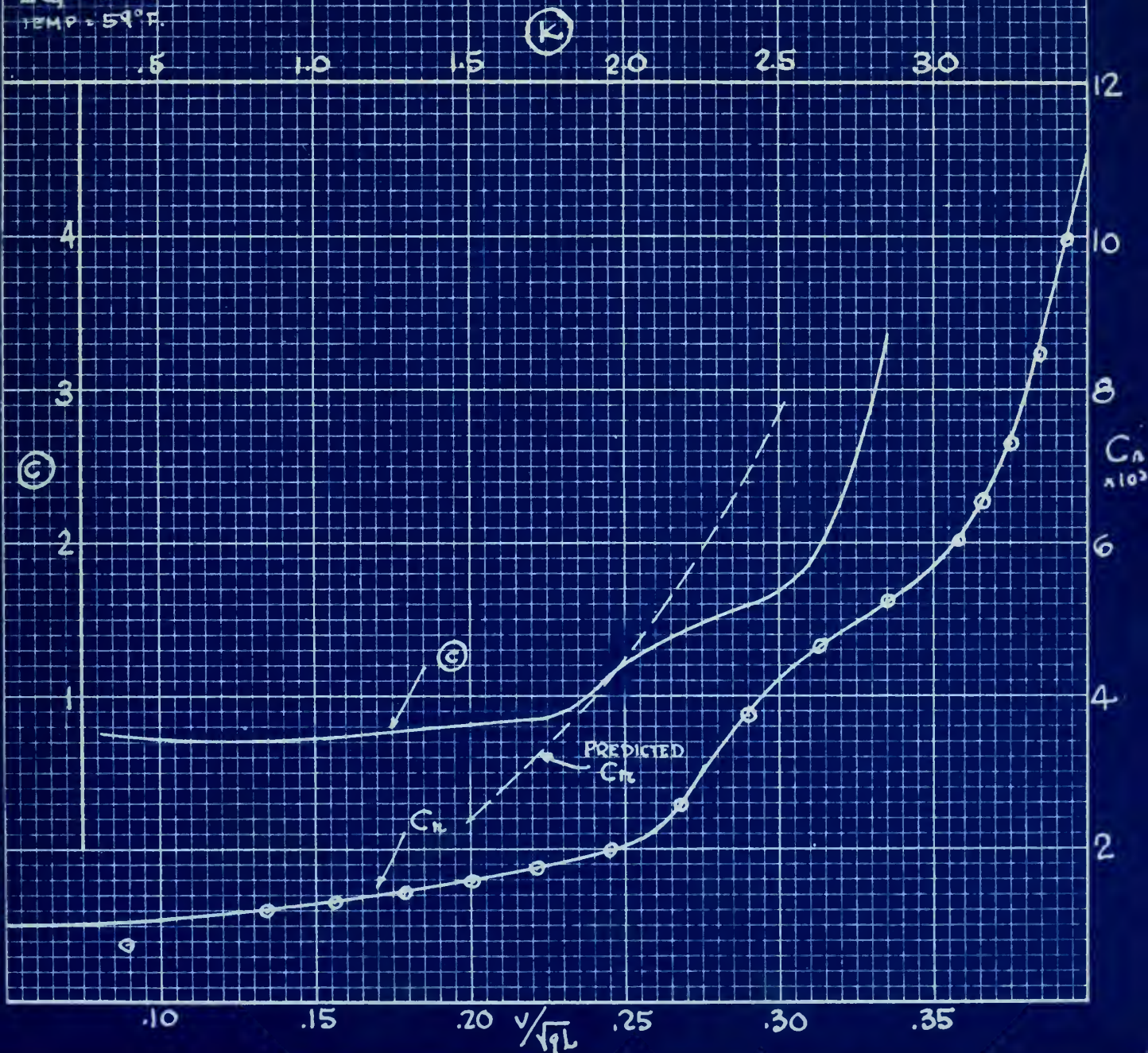


FIGURE VII

MODEL No. 4090

SERIAL No. 40

L = 11.11'

 $C_p = .677$

MODEL DATA

B = 2.485'

 $\frac{V}{\sqrt{gL}} = 10.30$

TEMP: 61°F

H = .917'

 $C_x = .821$ V_k R_f $\Delta = 800 \#$ $C_b = .556$

1.00

.52

S = 35.3940

 $C_{pv} = .717$

1.50

1.08

 $L/B = 4.47$ $C_w = .776$

1.75

1.44

 $B/H = 2.71$ $C_{sw} = 2.84$

2.00

1.60

2.25

1.80

2.50

2.00

2.75

2.20

3.00

2.40

3.25

2.60

3.50

2.80

3.75

3.00

4.00

3.20

4.25

3.40

4.50

3.60

APPENDAGES: RUDDER (SAND STRIP TURB. INCL.)

TYPE: TUG (USAE)

4.75

3.80

5.00

4.00

CORRECTED
FOR
TURBULENT
FLOW

C vs K FOR 400' SHIP

 $\Delta C_p = .0004$

TEMP = 59°F

(K)

.5 1.0 1.5 2.0 2.5 3.0

(C)

4

3

2

1

PREDICTED

 C_R C_R

12

10

8

6

4

2

 C_R
ALD

.10

.15

.20

 $\sqrt{gL}$

.25

.30

.35



FIGURE LIII

MODEL No: 4091

SERIAL No: 41

L = 11.11'

 $C_p = .586$

B = 2.92'

 $\nabla / \Delta = 12.15$

H = 1.077'

 $C_x = .794$ $\Delta = 10394$ $C_y = .465$

S = 37.64 ft

 $C_m = .648$

L/B = 3.81

 $C_{m2} = .717$

B/H = 2.665

 $C_{sw} = 2.77$

MODEL DATA

TEMP: 62°F

V _a	R _T
1.00	.56
1.50	1.16
1.75	1.57
2.00	2.08
2.25	2.65
2.50	3.38
2.75	4.24
3.00	5.40
3.25	7.18
3.50	9.14
3.75	11.35
4.00	14.79
4.25	18.17
4.50	21.70
4.75	26.80
5.00	32.45
5.25	39.80

APPENDAGES: RUDDER (TURBULENCE SAND STRIP)

TYPE: TUG (WMAE)

③ vs ④ FOR 400' SHIP

 $\Delta C_p = .0004$

TEMP: 59°F

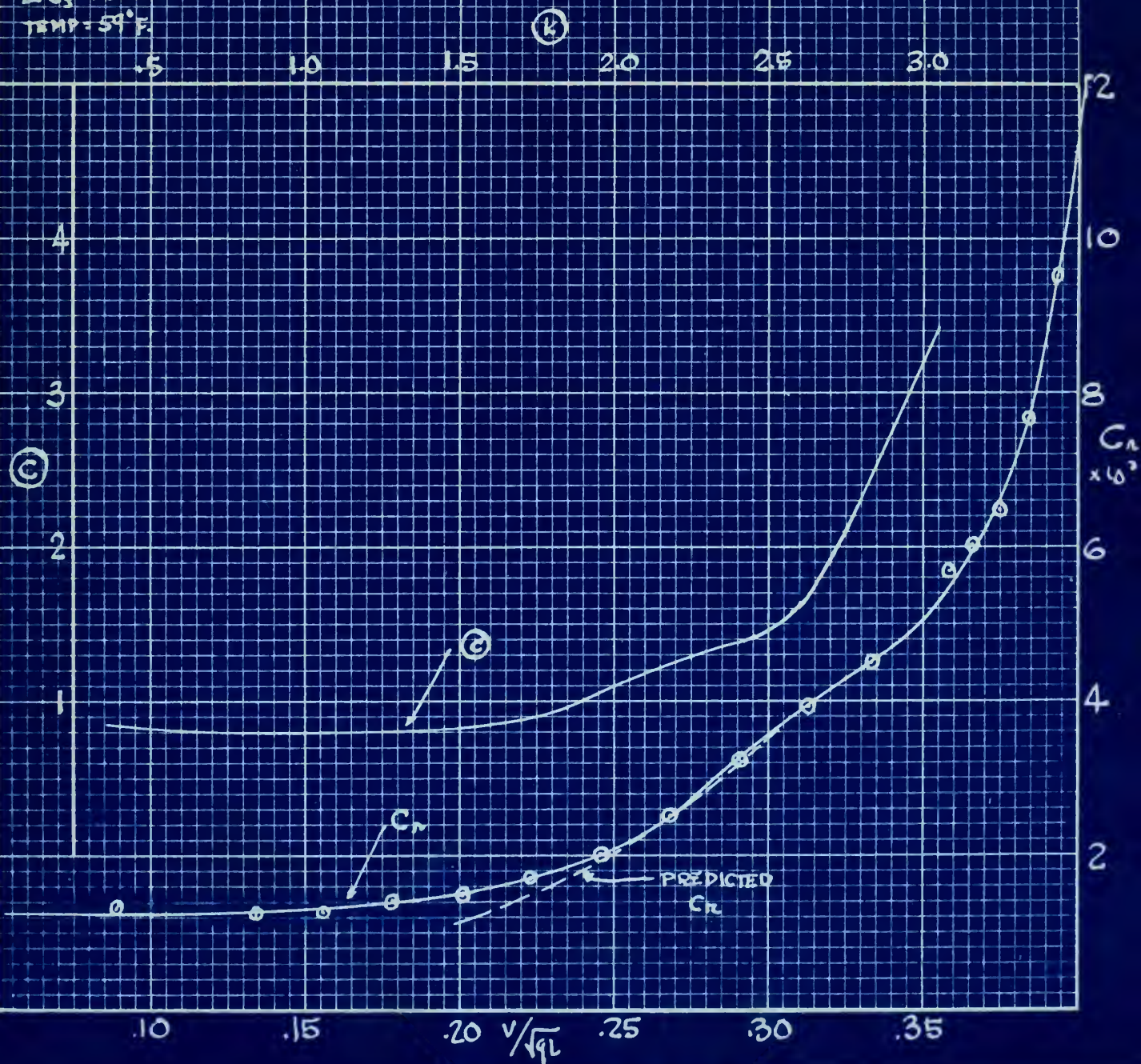


FIGURE LIV

MODEL No: 4093

SERIAL No: 42

 $L = 11.11'$ $C_p = .589$ $B = 3.065'$ $\nabla / (L^3) = 1375$ $H = 1.218'$ $C_x = .170$ $\Delta = 1175 \text{ lb}$ $C_b = .453$ $S = 39.512 \text{ d}$ $C_{pv} = .611$ $L/B = 3.62$ $C_w = .742$ $B/H = 2.517$ $C_{sw} = 2.74$

MODEL DATA

TEMP: 65°F

V_r	R_r
1.00	.61
1.50	1.23
1.75	1.65
2.00	2.15
2.25	2.75
2.50	3.45
2.75	4.22
3.00	5.07
3.25	6.00
3.50	7.05
3.75	8.25
4.00	9.60
4.25	11.10
4.50	12.75
4.75	14.55
5.00	16.50

APPENDAGES:

TYPE: TUG

RODDER:

(UBAE)

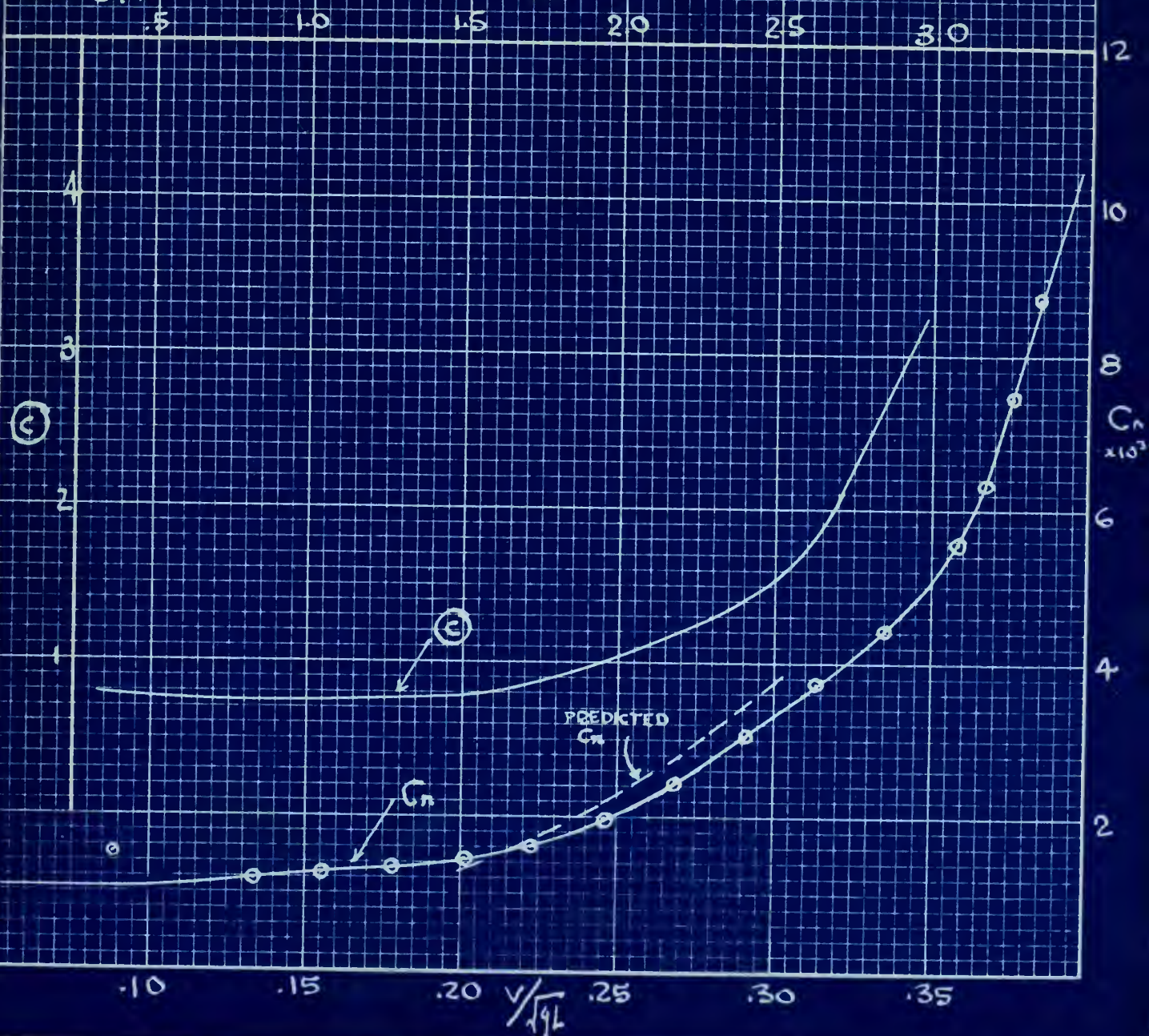
(SAND STRIP TURB.)

C vs K FOR 400' SHIP

 $\Delta C_s = .0004$

TEMP: 59°F

(K)



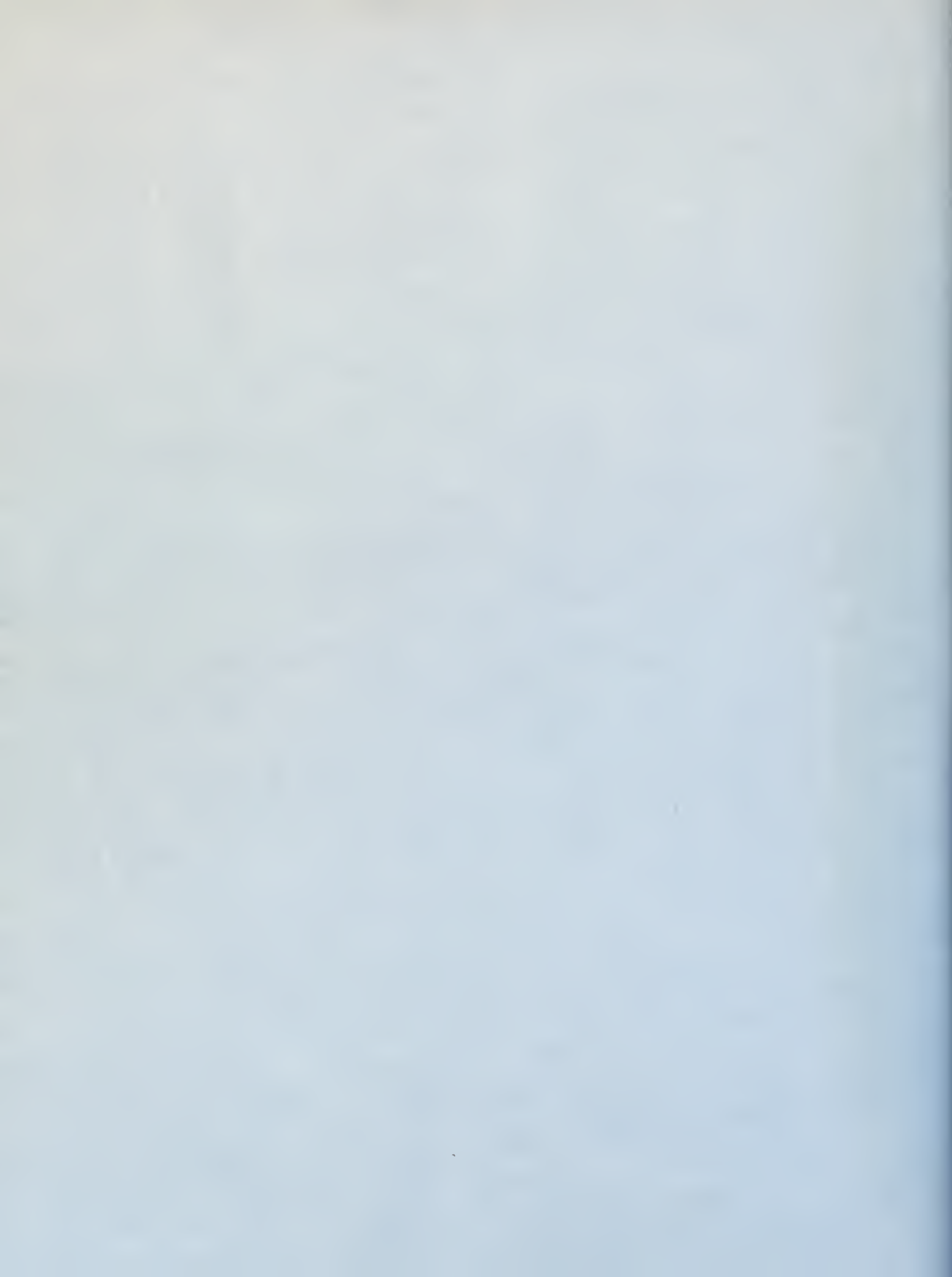


FIGURE IV

MODEL NO: 4094

SERIAL NO: 43

L = 11.11'

 $C_p = .592$

B = 3.042'

 $\nabla / \omega^3 = 16.18$

H = 1.233'

 $C_x = .898$ $\Delta = 1382 \#$ $C_b = .531$

S = 45.071'

 $C_{m1} = .713$ $L/B = 3.65$ $C_w = .745$ $B/H = 2.465$ $C_{sw} = 2.87$

MODEL DATA

TEMP: 65°F

V _r	R _t
1.00	.40
1.50	1.41
1.75	1.95
2.00	2.59
2.25	3.33
2.50	4.14
2.75	5.14
3.00	6.41
3.25	8.17
3.50	9.95
3.75	12.00
4.00	16.03
4.25	18.71
4.50	22.80
4.75	27.05

APPENDAGES: RUDDER (SAND STRIP TURN)

TYPE: TUG (USAE)

C vs R FOR 400' SHIP

 $\Delta C_s = .0004$

TEMP: 59°F

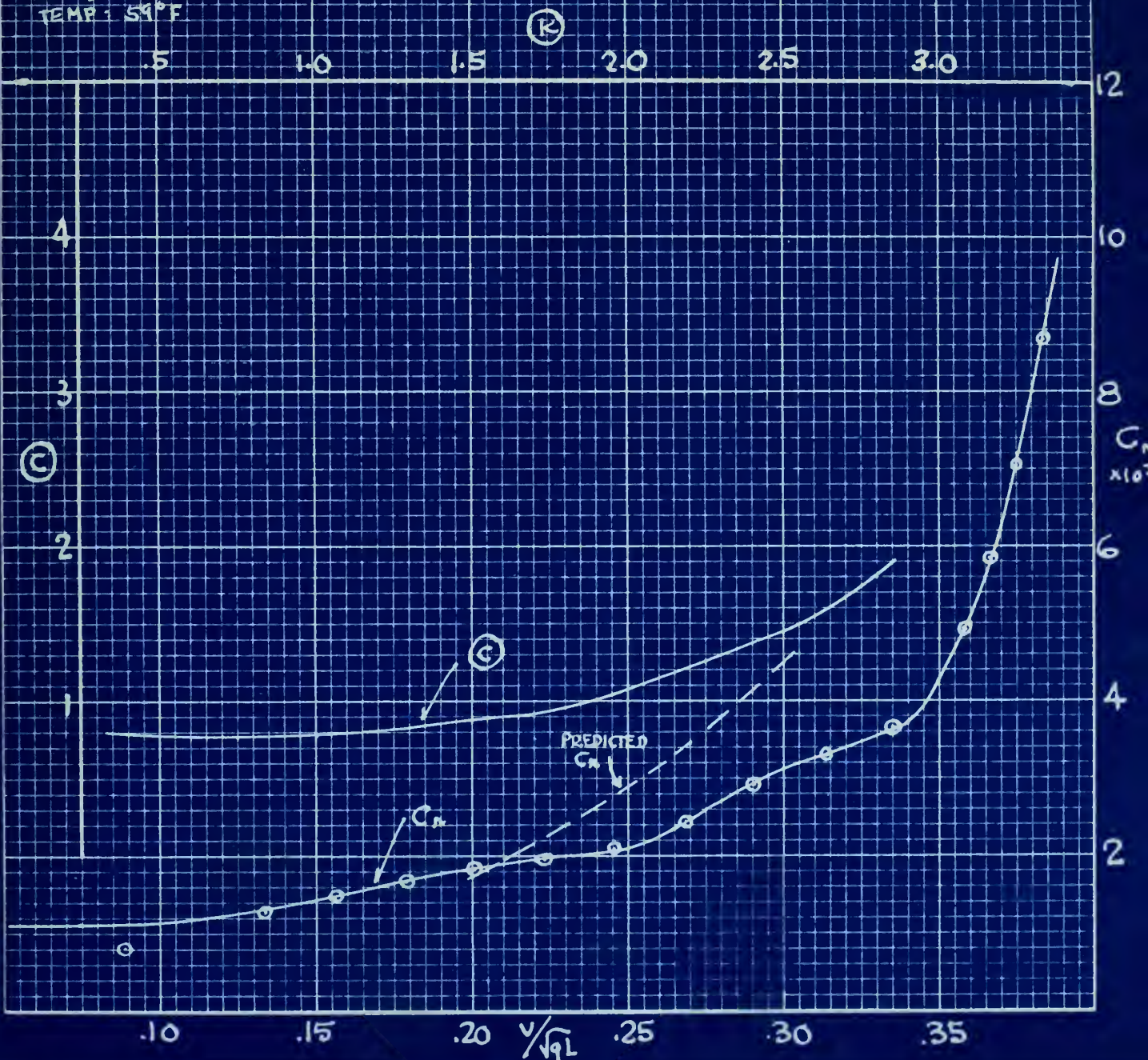




FIGURE IVT

MODEL No: 3138 C

SERIAL No: 44

L: 14.46'

 $C_p = .618$

B: 3.428'

 $\Delta/10^3 = 12.74$

H: 1.453'

 $C_x = .862$ $\Delta = 2392\#$ $C_b = .532$

S: 62.752

 $C_{pv} = .695$

L/B: 4.22

 $C_w = .766$

B/H: 2.36

 $C_{sw} = 2.67$

MODEL DATA

TEMP: 68°F

V_r	R_t
1.00	.76
1.50	1.69
2.00	3.04
2.50	4.37
2.75	4.96
3.00	5.58
3.10	5.52
3.20	5.60
3.30	5.64
3.40	10.30
3.50	11.20
3.60	12.67
3.80	16.50
4.00	20.60
4.20	24.58
4.50	26.67

APPENDAGES:

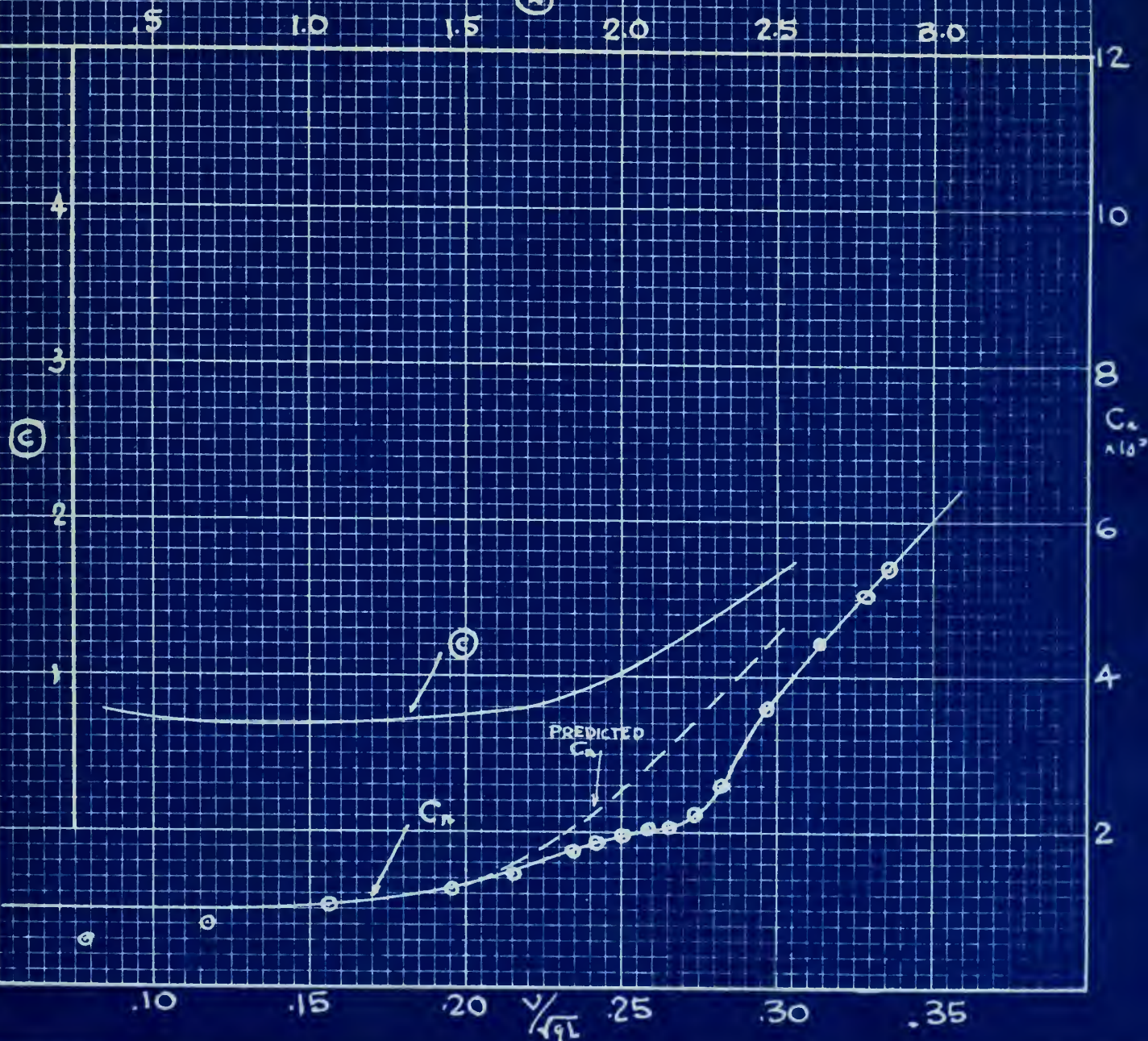
TYPE: TUG (N)

C vs K FOR 400' SHIP

 $\Delta C_s = .0004$

TEMP: 59°F

(K)



Appendix (F)

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5. GARDNER, H. J. "Methods for determining the oxygen content of the polymer." *Journal of Polymer Science*, 1954, 13, 1-10.
6. GARDNER, H. J. "Methods for determining the oxygen content of the polymer." *Journal of Polymer Science*, 1954, 13, 1-10.
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